“DESIGN OF EARTHQUAKE RESISTANT BUILDING USING SITE-SPECIFIC RESPONSE SPECTRA”

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology
in
Civil Engineering

By

ABU LEGO

Roll. No- 208CE213

DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008,
2010

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Under the guidance of

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2010

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INDIA

CERTIFICATE

This is to certify that the thesis entitled, **"DESIGN OF EARTHQUAKE RESISTANT BUILDING USING SITE-SPECIFIC RESPONSE SPECTRA"** submitted by **Mr. ABU LEGO** in partial fulfilment of the requirements for the award of **Master of Technology** Degree in **Civil Engineering** with specialization in **Structural Engineering** at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

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ACKNOWLEDGEMENT

I express my sincere gratitude and thankful to **Prof. S. Pradyumna and Prof. S. K. Das,** for their guidance and constant encouragement and support during the course of my work in the last one year. I truly appreciate and value their esteemed guidance and encouragement from the beginning to the end of this thesis, their knowledge and company at the time of crisis remembered lifelong.

My sincere thanks to **Dr. S. K. Sarangi,** Director and **Prof M. Panda,** Head of the Civil Engineering Department, National Institute of Technology Rourkela, for his maintained academic curriculum and providing necessary facility for my work. I am also very thankful towards all faculties and adviser of structural engineering department for their help and encouragement during the project. I am also thankful to all faculties of the Civil Department for their directly or indirectly involvement in my project work and my staying in NIT Rourkela.

I also thank all my batch mates who have directly or indirectly helped me in my project work especially to Shrikant Madhav Harle in the completion of this report. I also thank to Executive Engineer, PWD Pasighat, Superintendent Engineer, PWD Shillong, General Manager (Planning), NEEPCO Shillong and Executive Engineer, PWD Roing for their co-operation in providing me bore-hole data for various sites. I would also like to thank Mr. Sanjib Das, STAAD Technical support group and Vikram Gadicherla and Lavender Singh, Oasys technical support for helping by attending to my queries regarding the software that I had used for analysing the problem.

Finally yet importantly, I would like to thank my parents, who taught me the value of hard work by their own example. I would like to share this moment of happiness with my father, mother, brother & sister. They rendered me enormous support during the whole tenure of my stay in NIT Rourkela.

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CONTENTS

ABSTRACT

The energy released due to earthquake as seismic wave is propagated from the epicentre to the earth surface. This seismic wave causes the ground shaking which in turn causes severe damages to the structure overlying on the surface. During the propagation of this wave it has to travel through rock and soil types having different properties and of variable depth. According to the Indian standard for Earthquake resistant design (IS: 1893), the seismic force depends on the zone factor (Z) and the average response acceleration coefficient (S_a/g) of the soil types at thirty meter depth with suitable modification depending upon the depth of foundation. As per IS 1893, only three types of soils (soft, medium and hard) is considered without any consideration for the site specific soil parameters. In the present study an attempt has been made to generate response spectra using site specific soil parameters for some sites in seismic zone V, i.e. Arunachal Pradesh and Meghalaya and the generated response spectra is used to analyze some structures using commercial software STAAD Pro. The effect of soil properties, its types and the depth of soil in the response spectrum is discussed using Educational Version of the Oasys Siren software. The response spectrum is obtained from Siren 8.2 in which the physical properties and time history data of an earthquake i.e. North-East earthquake of September 10, 1986 which had the magnitude of 5.2 is considered. Finally comparisons have been made in between the structure designed by taking IS 1893:2002 response spectra under consideration with the structure designed by considering the generated response spectra for various types of soil for the seismic zone in terms of bending moment, shear forces and reinforcement.

The general conclusion for this study and the scope for the future on the above aspect are presented in Chapter 5.

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NOTATIONS

S_a/g	Spectral acceleration coefficient.
T	Time period in seconds.
S_A	Site-specific response spectra.
I_a	Input ground-motion spectral levels for the short period (acceleration).
I_v	Mid-period (velocity) bands for an implied reference ground condition.
F_a	Average short amplification factors with respect to the reference ground condition used for determination of I_a and I_v.
F_v	Mid-period amplification factors with respect to the reference ground condition used for determination of I_a and I_v.
x	Spectral decay exponent for the mid-period band.
G	Shear modulus.
E	Modulus of elasticity.
μ	Poisson's ratio.

CHAPTER 1

Introduction

CHAPTER - 1

Introduction

1.1 General:

Seismic design of buildings depends on peak ground acceleration values and shape of Response Spectra curves as depicted by relevant Building codes [1]. Underestimation of peak ground acceleration or wrong evaluation of response spectra may lead to grave consequences during the earthquakes. These two values depend upon earthquake magnitude and distance, as well on the regional propagation path properties and local geological conditions. At the present, there is no doubt that instead of standard design parameters, it is necessary to construct site-specific ones reflecting the influence from different magnitude events at different distances that may occur with certain probability during the lifetime of the construction, as well as the variety of local site conditions [2]. The influence of local geologic and soil conditions on the intensity of ground shaking and earthquake damage has been known for many years and has been shown by many earthquakes. On September 19, 1985 Michoacan, earthquake of magnitude 8.1 occurs with only moderate damage in the vicinity of its epicentre but the loss of lives and properties was catastrophic even though the buildings were design according to their codal provisions at Mexico city which was around 350 km away from the epicentre. Also the 1988 Spitak earthquake in Armenia, the 1995 Hyogo-Ken Nanbu (Kobe) earthquake in Japan, and the 1999 Ji-Ji earthquake in Taiwan was also of the same case [2]. In India also such cases were seen, the Dharmsala Earthquake of April 26, 1986, the North-East India Earthquake of September 10, 1986, the India-Burma Border Earthquake of January 10, 1990, the Uttarkashi Earthquake of October 20, 1991, the Chamba Earthquake of March 24, 1995, the India-Burma Border Earthquake of May 6, 1995, Xizang-India Border Earthquake of March 26, 1996, Chamoli Earthquake of March 29, 1999 and Kachchh Earthquake of January 26, 2001 [3]. All these places are situated in areas where earthquake are frequent and can be severe, so if any lapse in estimating the peak ground acceleration and response spectra for these area can be catastrophic which may lead to large scale destruction and property loss. In India as well the places located under zone V, the design for the structures has to make carefully in order to resist the forces that will be acting on the structure due to the local geologic and soil condition.

As shown in the Fig. 1.1 below the response of ground shaking is different for different types of soil. The magnitude in unconsolidated sediment is higher than in bedrock for same frequency. Thus the intensity of an earthquake is dependent on the types of soil irrespective of magnitude. The influence of soil deposits on seismic ground motion is enormous in terms of site amplification and thus structural damage and ground failures. Ground motion amplification is determined by two competing factors: impedance and attenuation of the soil deposits encountered along the seismic wave travelling path [4]. In current International Building Code, Edition 2003 [5] and IS 1893 (Part 1)- 2002 [6], the upper 30m surface soil deposits overlying the higher impedance earth crust is regarded as most relevant and important in characterizing the seismic behaviour of a site [7,8]. Assessment of the site amplification is primarily performed by using dynamic soil properties, which include stiffness (the shear modulus or the shear wave velocity) and attenuation (the damping ratio or the quality factor) [4]. The effect of frequency on dynamic soil properties, in particular attenuation is generally not considered in seismic analyses [9]. For rocks where the effect of frequency is slight, this practice is likely acceptable. However, for natural soils that exhibit greater frequency dependence, this practice may become undesirable. This is particularly true for attenuation, which is a known to be a function of frequency in the earthquake frequency band. For natural soils with fines content of only 5% or more, as the loading frequency increases, the shear modulus increases at an amount of approximately 6% per decade of loading frequency [10,11] and attenuation in the damping ratio does a function of the loading frequency with an obvious damping ratio trough (or, a quality factor hump) exist [12]. The damping ratios fall into a range of approximately 1–5%, or equivalently, the quality factors range from 10 to 50 [4].

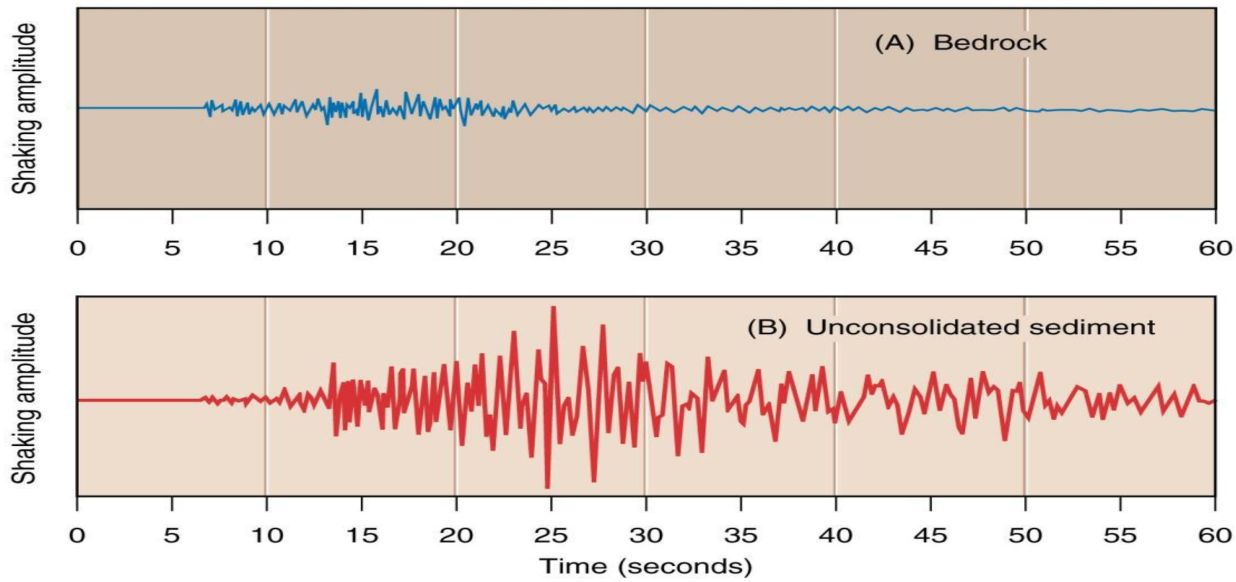


Fig. 1.1- Response of ground shaking for, a) Bedrock and b) Unconsolidated sediment.

The interaction between ground acceleration and structural systems through response spectrum [13] reflects frequency content, amplitude of ground motion and effect of subsequent filtering by the structure. Acceleration spectrum is a plot of natural period of vibration of a single degree of freedom (SDOF) oscillator with a specific value of damping versus peak absolute acceleration of oscillator mass when subjected to a base acceleration equal to the accelerogram (i.e., ground acceleration). The value of the spectral acceleration at zero periods, known as zero period acceleration (ZPA), is the PGA because oscillator is composed of infinitely stiff linear spring. The relative displacement response spectrum asymptotically approaches maximum ground displacement for highly flexible structure. This implies that the mass remains stationary for all practical purposes and only the ground moves as the linear elastic SDOF system is composed of spring of negligible stiffness. In between the two extreme periods, the value of spectral acceleration at a particular period is a constant multiplier, known as amplification factor, of peak ground acceleration. The amplification factor at short-period increases with increase of period and reaches a maximum at the sub-soil period and then it decreases with increase of period in general. The amplification factor for rocky site condition is higher than that of alluvium site condition at short periods and vice versa at long-periods. The amplification factor reduces with increase of hypo central distance from the site and amplification occurs at longer period [14]. These response spectra represent the effects of the amplitude of ground motion, their frequency characteristics, and to some extent the duration of ground motion [15]. As the seismic wave propagates through the soil column it becomes enriched in higher frequencies or in other words the higher frequencies (short periods) are highly magnified. It is seen where the response spectra of the ground surface have higher frequencies than those of the rocky outcrop. Above a period of about 1.0 s, however, the frequency contents of both rock and soil responses remain the same and there is no amplification beyond this period. This enrichment with higher frequencies as the wave propagates through the soil layers is indicative of the stiffness of the soil profiles. Had the soil columns been softer and thicker the response spectra would have been enriched with lower frequencies. The acceleration response spectra are also used to understand the effects of earthquake magnitudes and epicentral distances on the relative frequency content of ground motions. Smaller moment magnitudes have larger amplitude spectral values at short periods and larger magnitudes have larger amplitude values at longer periods. The relative spectral amplitude values increase with increasing moment magnitude as the period increases. In other words there is an increased enrichment of relative frequency contents with increasing moment magnitude [16].

1.2 Literature Review:

Borcherdt (1994) presented a comprehensive technique for calculating free-field, site-dependent, a response spectrum that utilizes, as one of its parameters, the average shear-wave velocity of the uppermost 30 m of soils at sites underlain by soils. This method which was derived from observations in California hence provides alternative procedures for estimating both input ground-motion spectral levels and amplification factors, depending upon available information. He suggested that the technique provides a general framework for design, as well as site-dependent building-code provisions and predictive maps of strong ground motion for purposes of earthquake hazards mitigation [8].

Silva and Costantino (2002) studied on the results which were recently obtained for generating site-specific ground motions needed for design of critical facilities. They followed the general approach in developing these ground motions using either deterministic or probabilistic criteria is specification of motions for rock outcrop or very firm soil conditions which was followed by adjustments for site-specific conditions. They include the development of an appropriate attenuation relation and their uncertainties, differences in expected motions between Western and Eastern North America, and incorporation of site-specific adjustments that maintain the same hazard level as the control motions, while incorporating uncertainties in local dynamic material properties. For tectonically active regions, such as the Western United States, sufficient strong motion data exist to constrain empirical attenuation relations for magnitude up to about 7 and for distances greater than about 10–15 km. The motions for larger magnitudes and closer distances are largely driven by extrapolations of empirical relations and uncertainties which need to be substantially increased for the cases. The Eastern United States, due to the paucity of strong motion data for cratonic regions worldwide, estimation of strong ground motions for engineering design is based entirely on calibrated models. The models were usually calibrated and validated in the western US where sufficient strong motion data are available and then recalibrated for applications to the eastern US. The recalibration entails revising the parameters based on available eastern US ground motion data as well as on the indirect inferences through intensity observations. The known differences in model parameters such as crustal structure between western US and eastern US were also accommodated and the procedures were examined and discussed [17].

Chandler and Lam (2004) had worked on the large magnitude earthquakes which were generated at source–site distances exceeding 100 km are typified by low frequency seismic waves. This ground shaking can be disproportionately destructive due to its high displacement, and possibly high velocity, shaking characteristics. Distant earthquakes represent a potentially significant safety hazard in certain low and moderate seismic regions where seismic activity is governed by major distant sources as opposed to nearby background sources. He found that majority of ground motion attenuation relationships currently available for applications in active seismic regions may not be suitable for handling long-distance attenuation, since the significance of distant earthquakes is mainly confined to certain low to moderate seismicity regions. Thus, the effects of distant earthquakes are often not accurately represented by conventional empirical models which were typically developed from curve-fitting earthquake strong-motion data from active seismic regions. He developed various well-known existing attenuation relationships in his paper, to highlight their limitations in long-distance applications. In contrast, basic seismological parameters such as the Quality factor (Q-factor) could provide a far more accurate representation for the distant attenuation behaviour of a region. His paper develops a set of relationships which provide a convenient link between the seismological Q-factor (amongst other factors) and response spectrum attenuation. The use of Q as an input parameter to the proposed model enables valuable local seismological information to be incorporated directly into response spectrum predictions [18].

Mammo (2005) presented the study of synthetic ground motion time histories have been generated at rock sites simulating earthquakes of moment magnitudes 6.8, 6.0 and 5.2 and epicentral distances of 25, 50, 80, 120 and 200 km. He applied these rock time histories as input motions at the base of the soil columns determined using surface seismic, a one-dimensional, equivalent-linear analysis was used to propagate the input motions through the soil columns to determine the ground motions at the ground surface. The computed acceleration time histories, response spectra and amplification spectra were most useful for design engineers [16].

Bakir et. all. (2007) examined the 7.2 magnitude of Duzce earthquake thoroughly giving special emphasis on fault normal and fault parallel components and response spectra. He found that the spectra obtained from Istanbul, the seismic demands are highest in the Fatih and Zeytinburnu districts and lowest in the Maslak district. Also the consequences of the signal processing with Butterworth filters are investigated for various records of the Duzce earthquake. For this they developed a complete strong-motion signal processing toolbox which can process the data with alternative techniques. Their current Turkish Earthquake Resistant Design Code does not take the near fault effects into account and new design response spectra for Turkey were proposed based on a previous attenuation relationship of the authors on 301 horizontal accelerograms from different earthquakes and according to the FEMA 356 specifications. They then proposed a design response spectrum which may be considered for implementation in important engineering structures since it accounts for distance and site effects [19].

Meng (2007) presented one-dimensional earthquake ground motion simulation with frequency-dependent dynamic soil parameters, which include shear wave velocity and quality factor, is performed within the frequency band between 10^{-2} and 30 Hz. For the simulation, the general frequency-dependent dynamic soil properties were obtained by using a new non-resonance technique on various soils. He made comparisons between transfer functions involving frequency-dependent and independent dynamic soil parameters which indicate that soil amplification throughout the considered frequency range is sensitive to the values of the dynamic soil parameters, in particular to the quality factor. The simplification of frequency-dependent dynamic soil parameters into constants, which prevail as a convenient practice, incurs large amplitude distortion. Thus he demonstrates that the dynamic properties of soils play an important role in the near surface earthquake ground motion analyses and has to be used in the same way as how they were measured [4].

Hao and Gaull (2009) performed the probabilistic seismic hazard analysis to determine two alternate magnitude-distance combinations for the 475 yr event, and the worst-case scenario event in Perth, Western Australia. Regional strong ground motion time histories on rock sites are used to modify an eastern North America seismic model to suit southwest Western Australian conditions. His model is used to do stochastically simulate a set of 475 yr design events and a set of worst-case scenario event for rock sites in the Perth metropolitan area. He then used the simulated time histories as input to typical soft soil sites in the Perth metropolitan area to estimate surface ground motions. The spectral accelerations of the ground motions on rock and soil sites were calculated and compared with the corresponding design spectrum which was defined in the current and previous Australian earthquake loading code. He then made the discussions on the adequacy of the code spectra and the differences, along with implications on structural response and damage [20].

1.3 Present study:

The present study leads to the study of relationship between local soil conditions and damaging ground motion. The study includes the generation of site-specific response spectra for Zone V for two north-east states i.e. Arunachal Pradesh and Meghalaya. These states rest on Himalayan faults and the damage can be catastrophic if earthquake occurs and due provisions are not taken while constructing any structure in these areas. In Himalayan belt metamorphic type, gravelly soils and sandy soils of geology prevails and according to the Borcherdt [8], the shear wave velocities for this type of rock is very high for the former and also in loose to semi consolidated soil the ground motion amplifies. So as per the IS codal provision [6] the response spectra given is based upon three types of soil rock or hard soil, medium soil and soft soil, which is taken as the average values for all the respective zones, which is relatively inadequate as the strong ground motion is dependent to the geometry and material properties of the subsurface materials, on site topography and on the characteristics of the input motion like shear wave velocities, shear modulus, etc.

CHAPTER 2

IS 1893:2002 Codal Provisions

CHAPTER – 2

IS 1893:2002 CODAL PROVISIONS

2.1 Dynamic Analysis:

Dynamic analysis is performed to obtain the design seismic force, and its distribution to different levels along the height of the building and to the various lateral load resisting elements, for the following buildings:

a) Regular buildings - Those greater than 40 m in height in Zones IV and V, and those greater than 90 m in height in Zones II and III.

b) Irregular buildings - All framed buildings higher than 12 m in Zones IV and V, and those greater than 40 m in height in Zones II and III.

2.2 Response Spectra:

The response spectra considered according to the Indian Standard for design is as shown in Figure 2.1 where consideration for different type of soil is based on appropriate natural periods and damping of the structure and these curves represent free ground motion.

The spectral acceleration coefficient i.e. (S_a/g) taken as per IS: 1893 (Part 1): 2002 is as follows, which is consider for designing the structure.

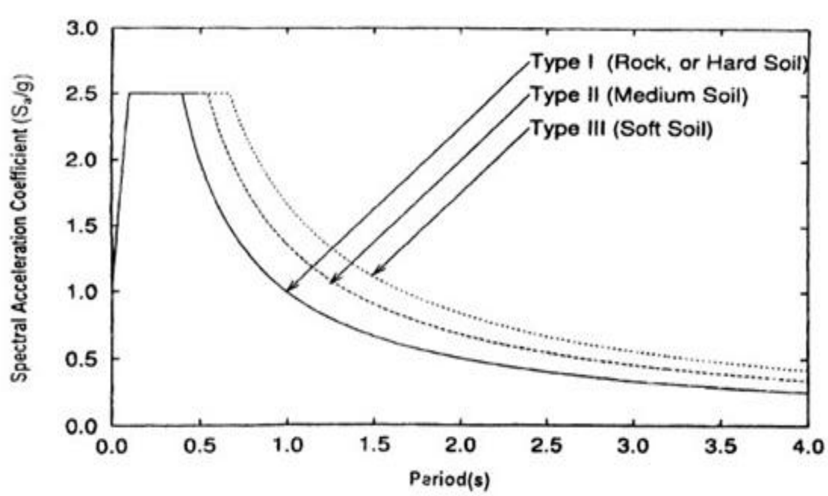


Fig. 2.1- Response Spectra for rock and soil sites for 5% damping

For rocky, or hard soil sites,

$$\frac{Sa}{g} = \begin{cases} 1 + 15T & 0.00 \leq T \leq 0.10 \\ 2.5 & 0.10 \leq T \leq 0.4 \\ \dfrac{1.00}{T} & 0.40 \leq T \leq 4.00 \end{cases}$$

For medium soil sites,

$$\frac{Sa}{g} = \begin{cases} 1 + 15T & 0.00 \leq T \leq 0.10 \\ 2.5 & 0.10 \leq T \leq 0.55 \\ \dfrac{1.36}{T} & 0.55 \leq T \leq 4.00 \end{cases}$$

For soft soil sites,

$$\frac{Sa}{g} = \begin{cases} 1 + 15T & 0.00 \leq T \leq 0.10 \\ 2.5 & 0.10 \leq T \leq 0.67 \\ \dfrac{1.67}{T} & 0.67 \leq T \leq 4.00 \end{cases}$$

2.3 Types of Soil:

According to the 1893 code guidelines the following type of soil were considered:

a) For rocky or hard soil- It is well graded gravel and sand gravel mixtures with or without clay binder, and clayey sands poorly graded or sand clay mixtures (GB, CW, SB, SW, and SC) having N above 30, where N is the standard penetration value.

b) For medium soil- All soils with N between 10 and 30, and poorly graded sands or gravelly sands with little or no fines (SP), with N > 15.

c) For soft soil- All soils other than SP with N<10.

These provisions were not sufficient for designing structure as the response spectra generated according to IS code is based upon three types of soil rock or hard soil, medium soil and soft soil, which is taken as the average values for all the respective zones. But the local soil condition is different for the various places and the peak ground acceleration and the response spectra generated will be different for different cases, for the strong ground motion is dependent to the geometry and material properties of the subsurface materials, on site topography and on the characteristics of the input motion like shear wave velocities, shear modulus, etc.

CHAPTER 3

Methodology

CHAPTER – 3

Methodology

3.1 Present Methodology:

Borcherdt [8] had given procedure for estimating the site-dependent response spectra which are based on empirical correlations between soil properties and mean shear-wave velocity. It is intended to be universally applicable. Using his soil classification scheme, free-field, site-specific response spectra (with 5% damping), S_A can be derived for sites using the formula:

Free-field, site-specific response spectra with 5% damping, S_A, are defined as:

$$S_A = \text{Minimum for each period T of } \begin{cases} I_a F_a \\ I_v F_v / T^x \end{cases}$$

Where,

I_a and I_v are input ground-motion spectral levels for the short-period (acceleration) and mid-period (velocity) bands for an implied reference ground condition.

F_a and F_v are average short and mid-period amplification factors with respect to the reference ground condition used for determination of I_a and I_v.

T represents period in seconds, and

x is the spectral decay exponent for the mid-period band.

3.2 Shear Modulus of Soil:

Classification of site was considered by the physical property criteria i.e. by the description of the subsurface soil property. These physical property information like thickness and type of soil present was gathered by doing borehole experiment on the site for up to the depth of 30 m and based on the Borcherdt classification criteria the mean shear-wave velocity were taken for different type of soil. Shear modulus was calculated for each soil type by the formulation given

$$G = \frac{E}{2(1+\mu)}$$

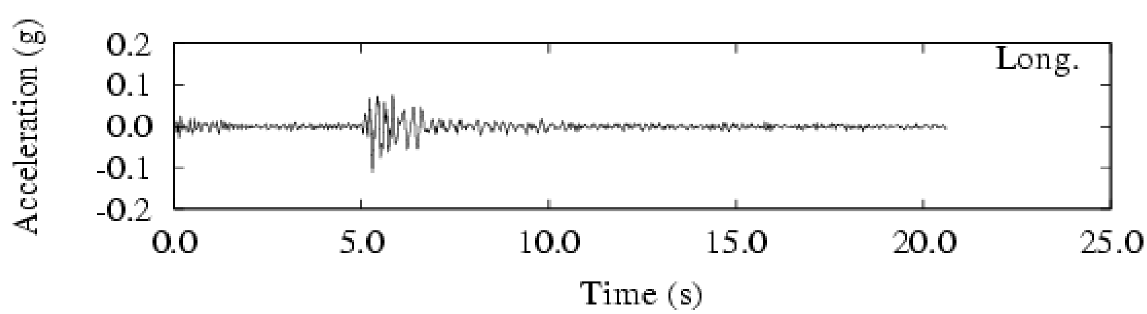
The shear-wave velocity and the shear modulus of each soil particle were generated.

3.3 Data Collection:

Data were collected from different sites from two states of India i.e. Arunachal Pradesh and Meghalaya. In these site boreholes experiment was done and the thickness of the different soil particles and its physical property was collected and tabulated. These experiments were mostly done by private consultants for government agencies to know the subsoil strata. In these data only the physical property i.e. the sub soil strata were given with the thickness but no shear-wave velocity experiment was done. So to obtain this shear-wave velocity comparison had been made with Borcherdt soil classification and corresponding shear-wave velocity was obtained. Soil data available are mostly of bridge site. The borehole experiment is not common in these areas for structures due to the increase in overall cost of construction. Data are also missing for some places for which the assumed values were considered for those kind of conditions.

3.4 Input Bedrock Motion:

Also the appropriate time history data were selected for this region which had occurred at Shillong region (Epicentre- 25.43^0 N, 92.08^0 E) on September 10, 1986 of magnitude 5.2, as shown below. This data was taken as the input bedrock motion for the generation of response spectra in these areas [16].



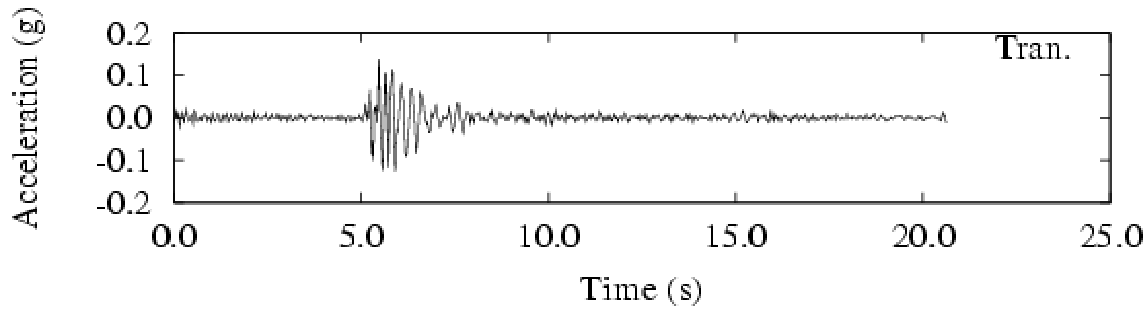


Fig. 3.1- Input Bedrock motion

3.5 Response Spectra from Oasys Siren Software:

Oasys Siren is a computer software use to analyse the response of a one-dimensional soil column to an earthquake motion at its base. The software allows the user to understand how the seismic wave behaves in magnitude and frequency in various types of soil for different plasticity index. The software uses the physical and material properties such as bedrock level, density, shear wave velocity, strain degradation curve for different soil types and the bedrock motion as the input for the generation of various types of text and graphical output like Input time history, Stress-Strain curve for any element in the soil profile, Relative displacement at various elevations at any time, Base response spectrum and surface response spectrum, Spectral ratio (surface/bedrock) and Displacement, velocity and acceleration time response for any node.

The input data i.e. shear-wave velocity, shear modulus and the time vs. acceleration that were obtained through various method are use in Oasys Siren software so that the response spectra required for the designing for a structure are obtained.

3.6 Response spectrum analysis of structure using STAAD Pro Software:

STAAD.Pro is one of the structural engineering software products for 3D model generation, analysis and multi-material design. It has an intuitive, user-friendly GUI (graphical user interface), visualization tools, powerful analysis and design facilities and seamless integration to several other modeling and design software products. This software is used for static or dynamic analysis of bridges, containment structures, embedded structures (tunnels and culverts), pipe racks, steel, concrete, aluminum or timber buildings, transmission towers, stadiums or any other simple or complex structure.

Two structures were considered for analysis the structure, there 3-D space frame models for a 10 storey and a 3 storey buildings were generated in STAAD Pro. The response spectrum analysis was carried out by the IS 1893 response spectrum method as well as for the different types of soil which were found at the sites. Finally the axial load, displacement and the bending moment of column and beams for different floors were compared between the IS 1893 response spectrum method and all the other types of soil.

The general diagram for the two structures is shown below. The heights of each floor were considered as 3 m. The dynamic analysis for these structures were done by STAAD Pro software and the response spectra generated by Oasys Siren for all the different types of soil are provided to STAAS Pro for response spectrum analysis and various results are obtained such as Maximum Displacement, Axial load and Bending Moment.

10 Storey Structure:

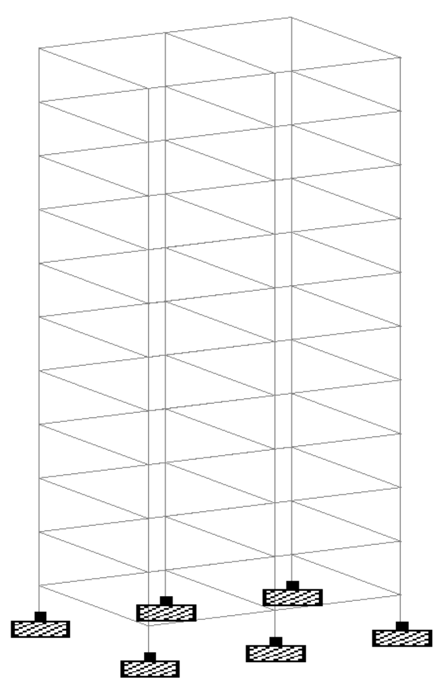


Fig. 3.2- General diagram of 10 storey building.

3 Storeyed structure:

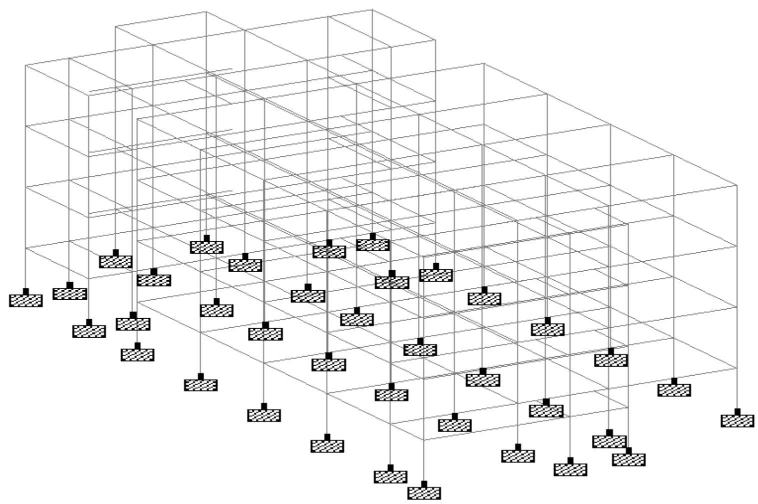


Fig. 3.3- General diagram of 3 storey building.

CHAPTER 4

Results and Discussions

CHAPTER - 4

Results and Discussions

4.1 Selection of site:

The data of soil profile which was found out by doing borehole experiment were collected from different sites from government agencies which are dealing with construction in these areas. The sites are listed below

- Proposed bridge site over the river **Sisiri** which is situated at a distance of 15 km from Bijari town in Arunachal Pradesh
- Proposed bridge site over **Jou Korong** which is situated at a distance of 6.35 km from Ruksin in Arunachal Pradesh
- Proposed bridge site over **Myntang River** which is situated at Sahsniang-Kuruliya road in Meghalaya

4.2 Soil type:

The different types of soil that are prevalent in these areas which were found out after doing the borehole experiment in these sites are listed below-

- Poorly graded gravels
- Sandstone
- Sandy clay
- Silt
- Well graded sand

4.3 Response spectrum for different types of soil at different PI values:

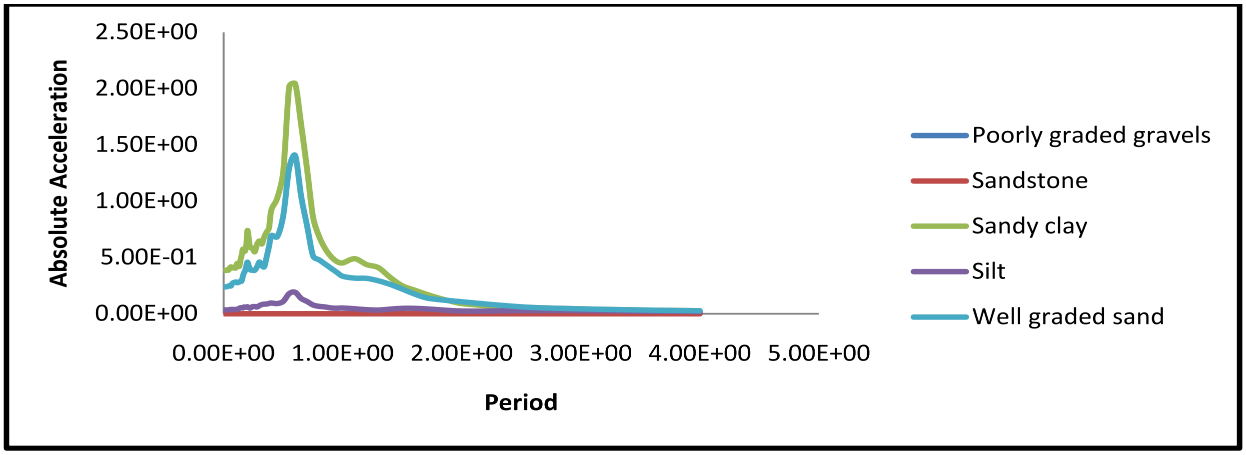


Fig. 4.1-Response spectrum in longitudinal direction at 0 Plasticity Index.

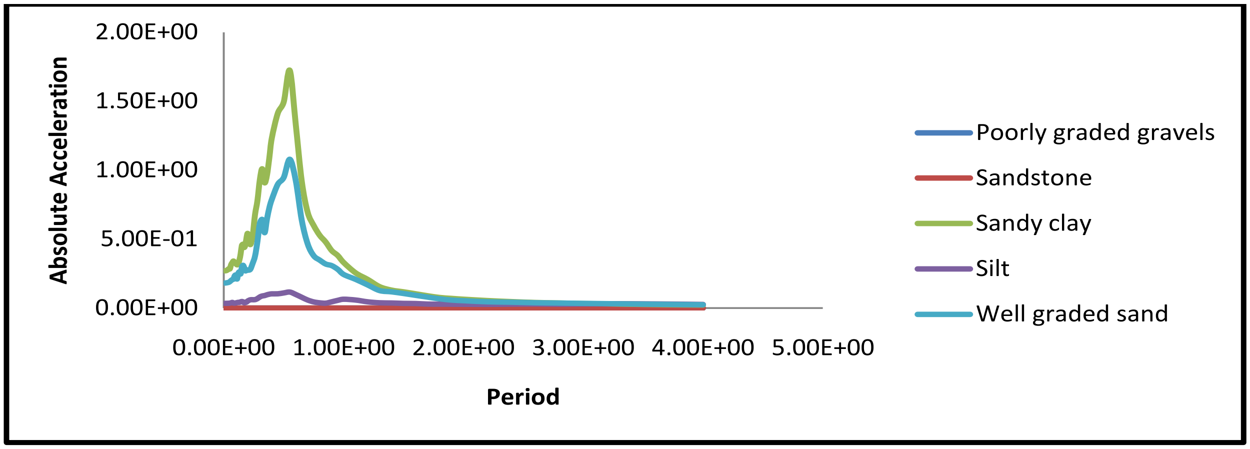


Fig. 4.2-Response spectrum in transverse direction at 0 Plasticity Index.

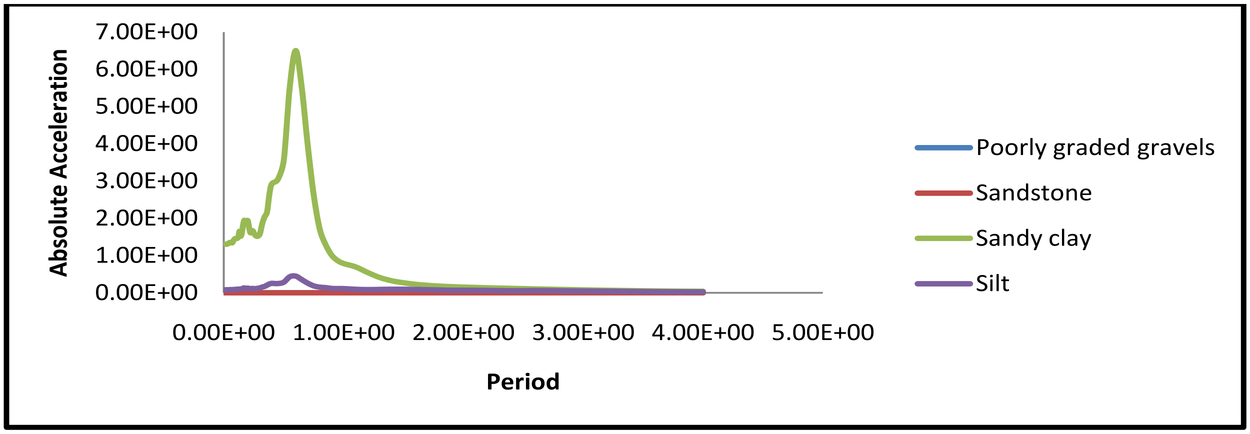


Fig. 4.3-Response spectrum in longitudinal direction at 30 Plasticity Index.

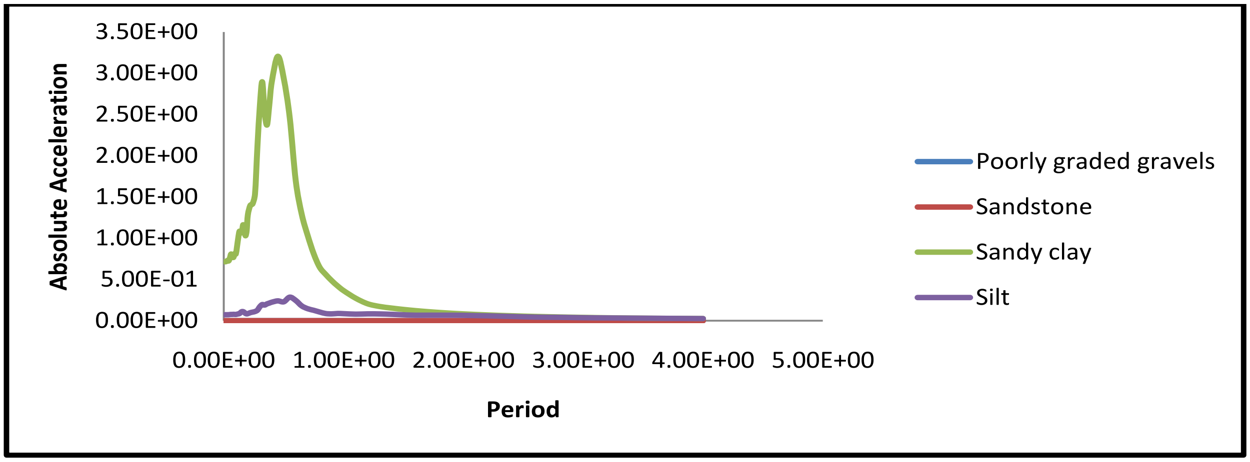


Fig. 4.4-Response spectrum in transverse direction at 30 Plasticity Index.

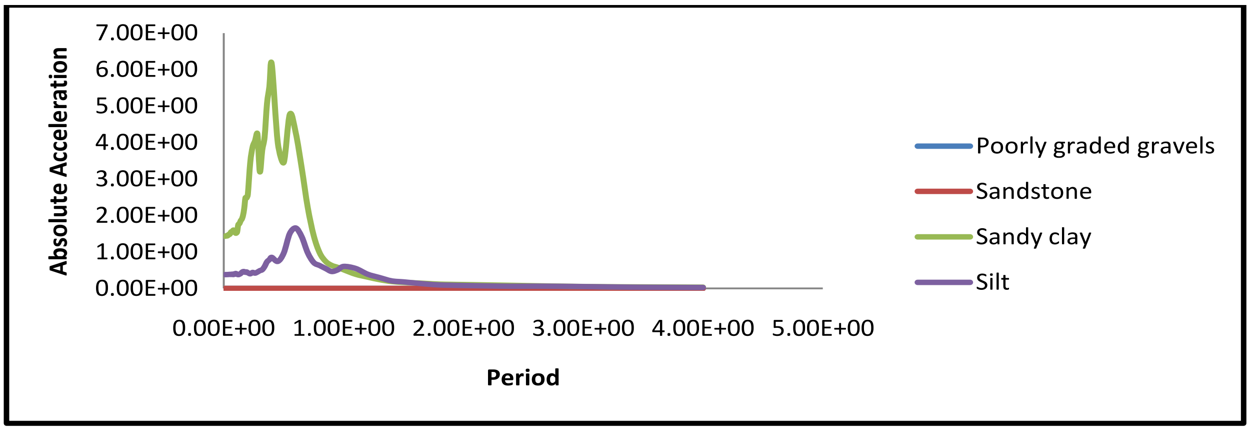


Fig. 4.5-Response spectrum in longitudinal direction at 200 Plasticity Index.

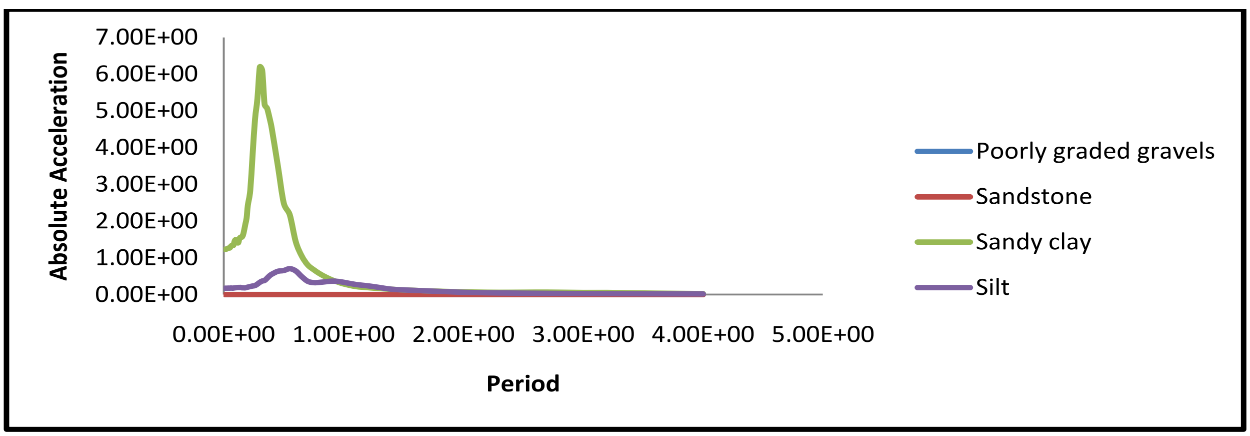


Fig. 4.6-Response spectrum in transverse direction at 200 Plasticity Index.

From the figs. 4.1, 4.2, 4.3 4.4, 4.5 and 4.6 it had been found that the response spectral graph for the Sandy Clay is highest in comparison to other type of soil and for the Gravels and Sandstone it is almost negligible. As the Plasticity Index value of the soil gets higher the spectral response for each soil gets high. So the plasticity index value in proportional to the response spectra for a particular type of soil. And for higher Plasticity Index value i.e. 30 and 200 PI, the spectral response at 0.5 sec. has higher values in compare to the codal response spectrum (see fig. 2.1). So the design horizontal seismic coefficient for a structure will have higher value thus subsequently increasing the design seismic base shear value along any principal direction.

4.4 Response spectrum for different types of soil in various directions:

Response spectrum generated for different types of soil and earthquake of North-East India Earthquake of September 10, 1986 in different direction-

1) **Poorly graded gravels**-

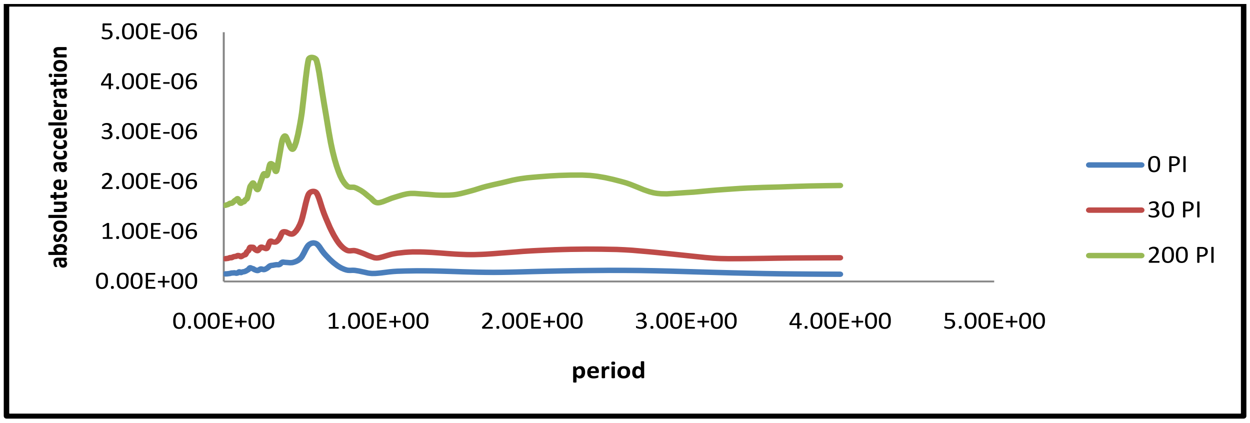


Fig. 4.7- In longitudinal direction

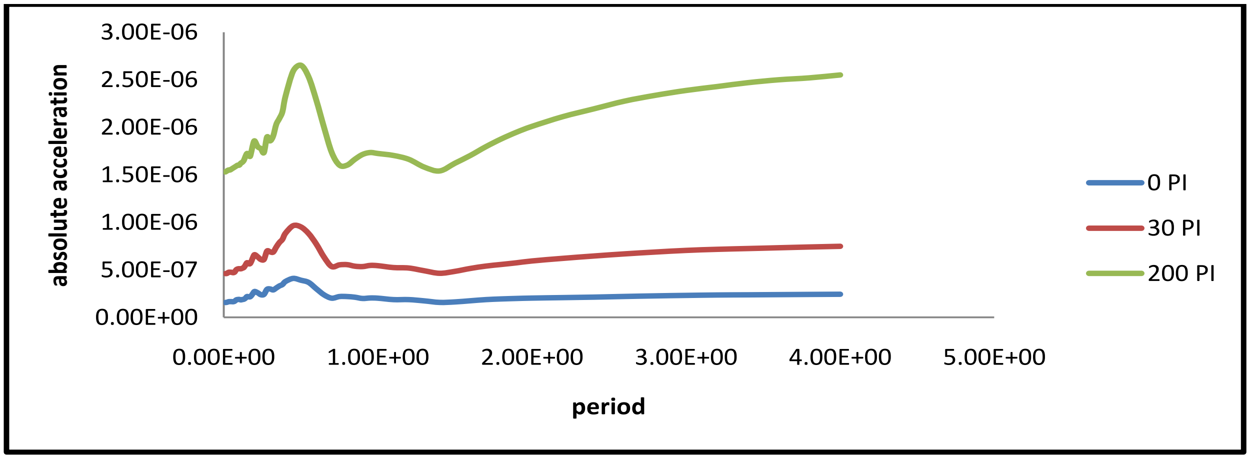


Fig. 4.8- In transverse direction

2) **Sandstone-**

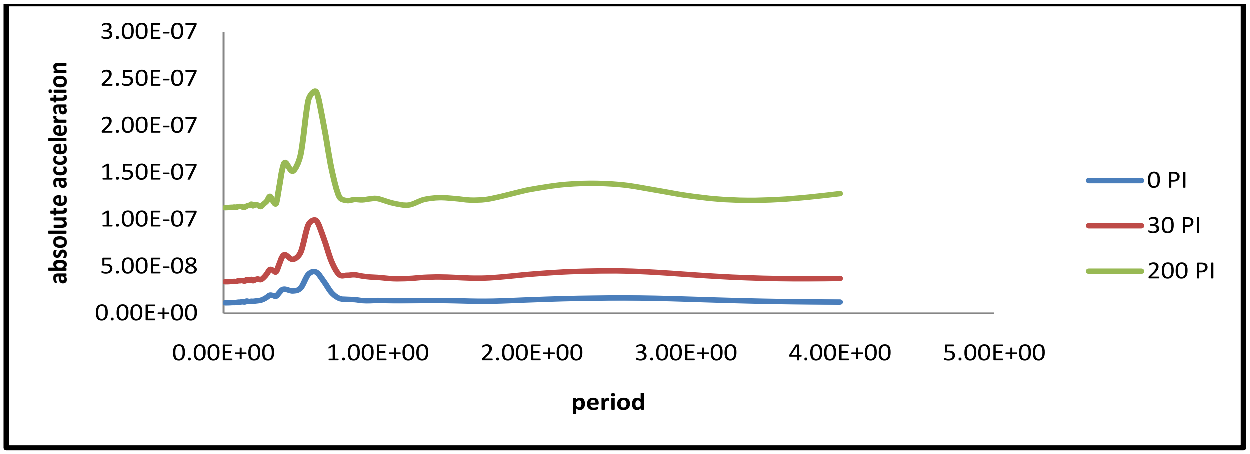


Fig. 4.9- In longitudinal direction

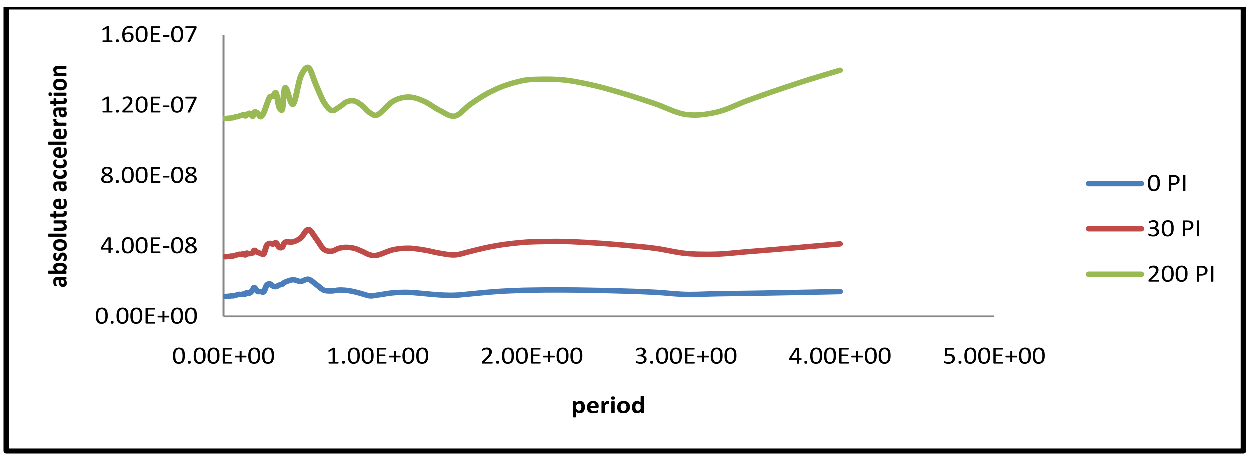


Fig. 4.10- In transverse direction

3) **Sandy clay-**

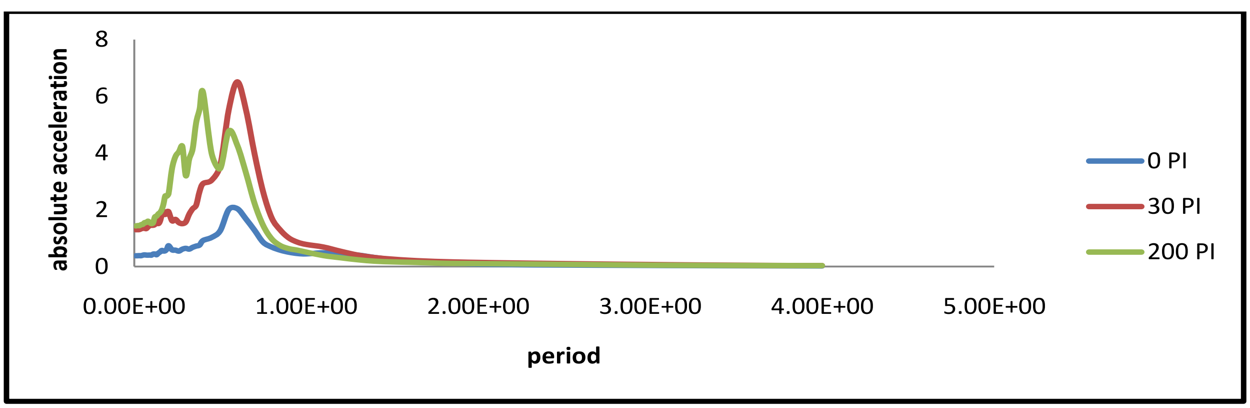


Fig. 4.11- In longitudinal direction

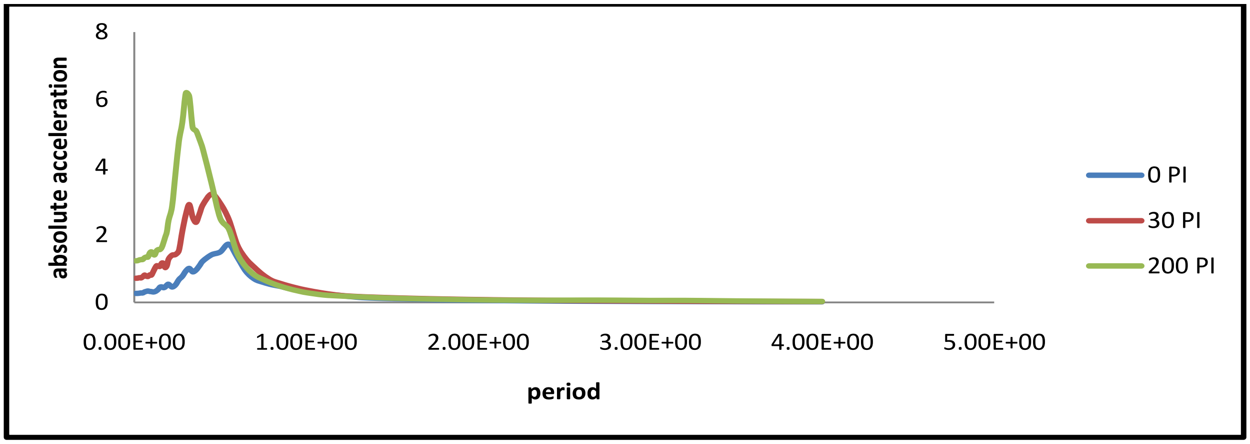


Fig. 4.12- In transverse direction

4) **Silt-**

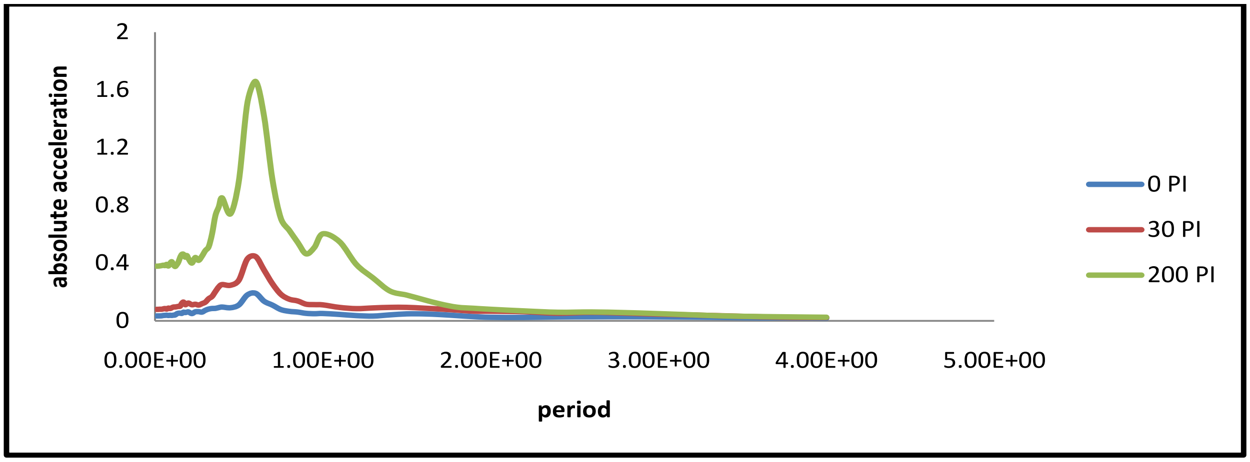


Fig. 4.13- In longitudinal direction

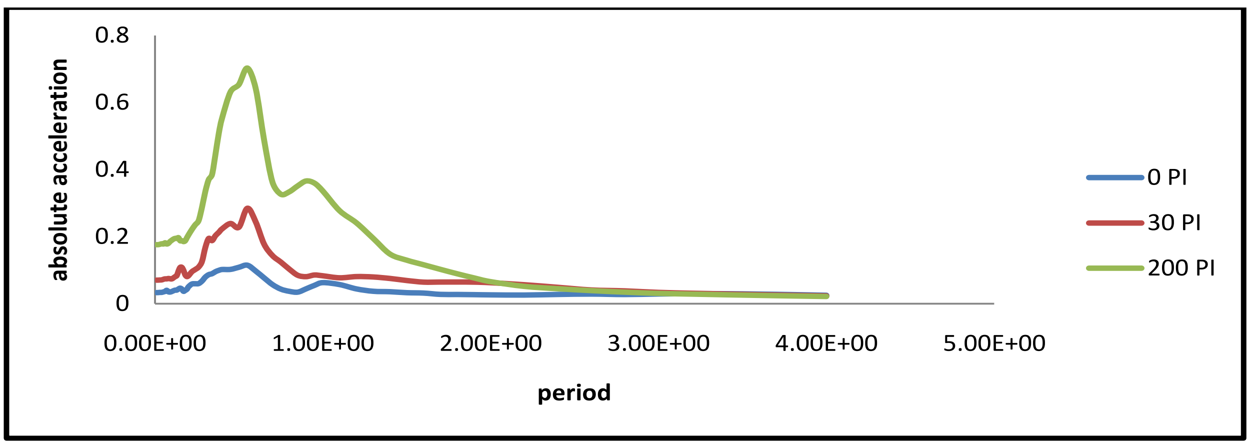


Fig. 4.14- In transverse direction

5) **Well graded sand-**

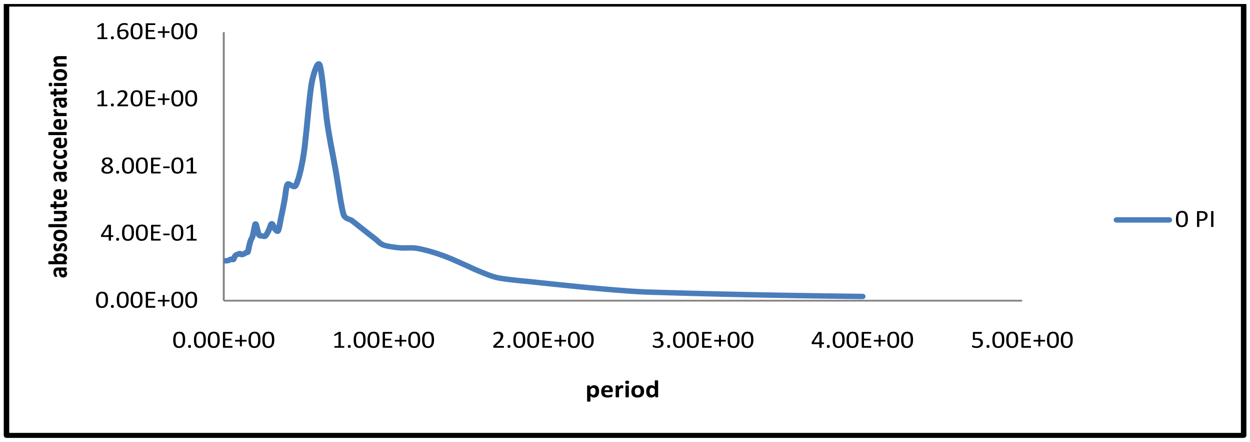


Fig. 4.15- In longitudinal direction

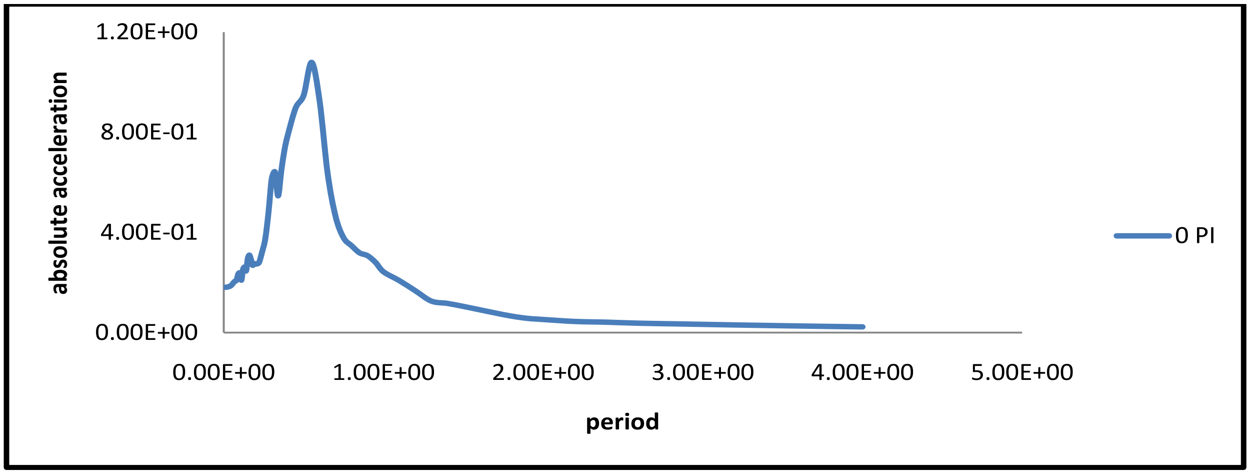
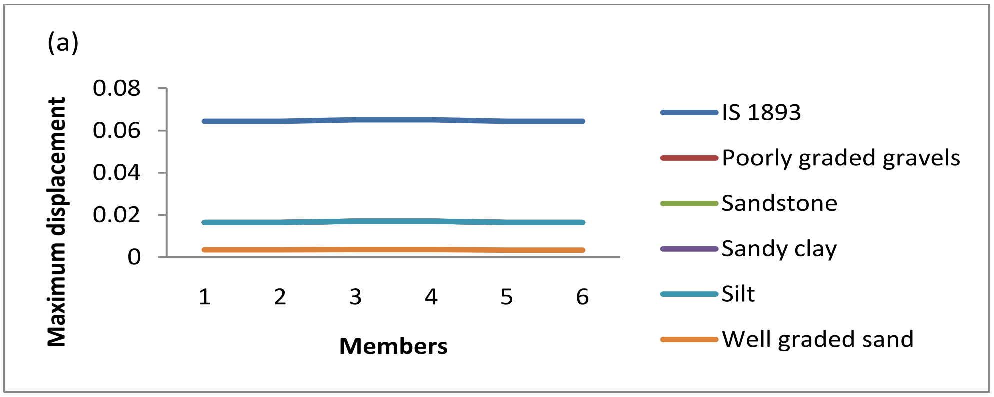


Fig. 4.16- In transverse direction

4.5 Response spectrum analysis of multi storey building:

The dynamic analysis of two building (as explained before) was done with using the response method using the codal response spectra for hard soil type and for different types of soil found, which is generated by the Oasys Siren. The comparison was made between the two structures in terms of Maximum displacement, axial load and Bending Moment for these two types of structure and the result was tabulated. The maximum displacement and Bending Moment diagram for each structure is also shown.

Dynamic analysis by response spectrum method for 10 storey structure-



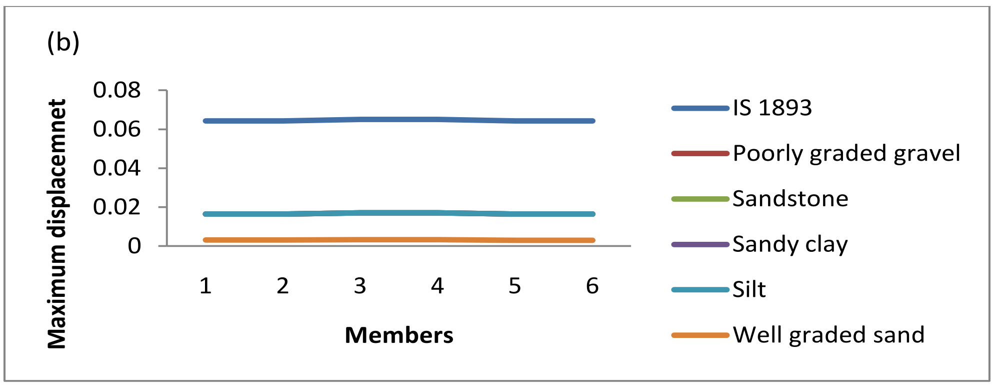
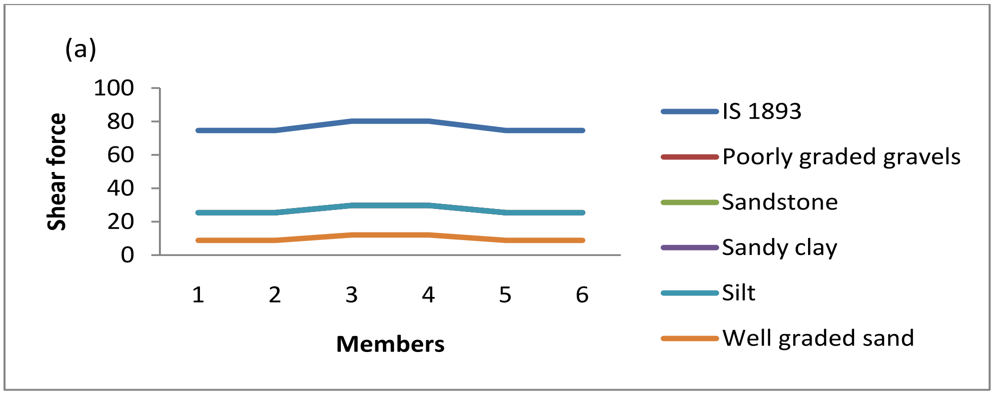


Fig. 4.17: Maximum displacements of column in cm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.17 it can be seen that the maximum displacement as per IS 1893 soft soil is having higher displacement in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same displacement values and the well graded sand has the least for both the direction. Also the value remains the same in both the direction of propagation.



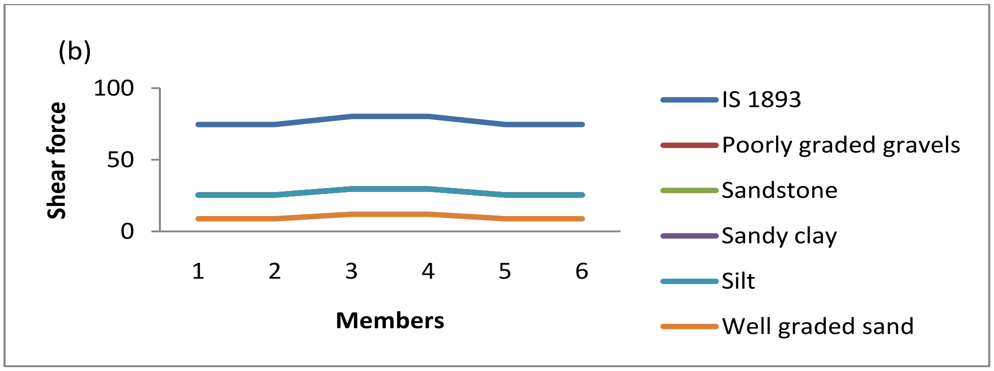
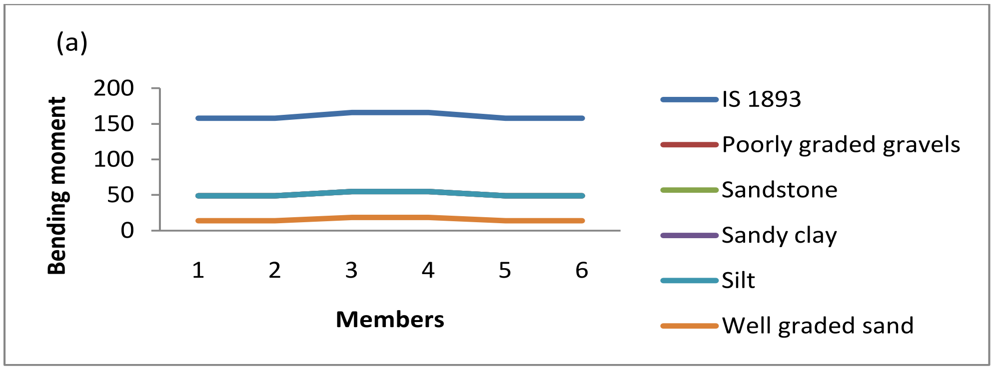


Fig. 4.18: Shear forces of column in KN with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

Similarly as per 4.18 the shear forces for column members have higher values as per IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values and the well graded sand has the least for both the direction. Also the value remains the same in both the direction of propagation.



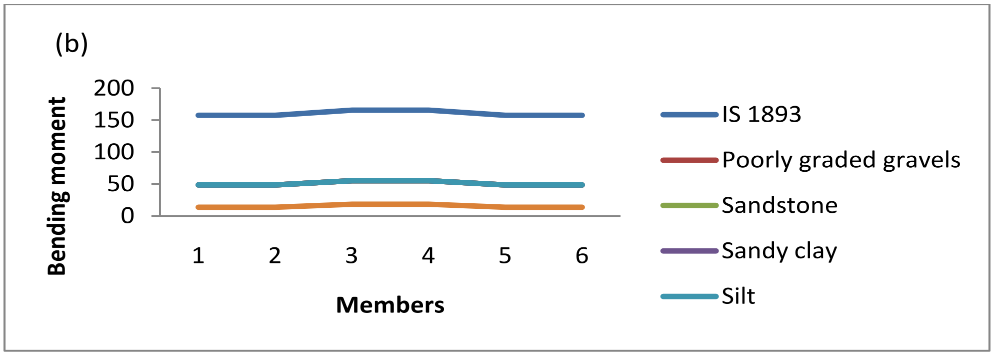
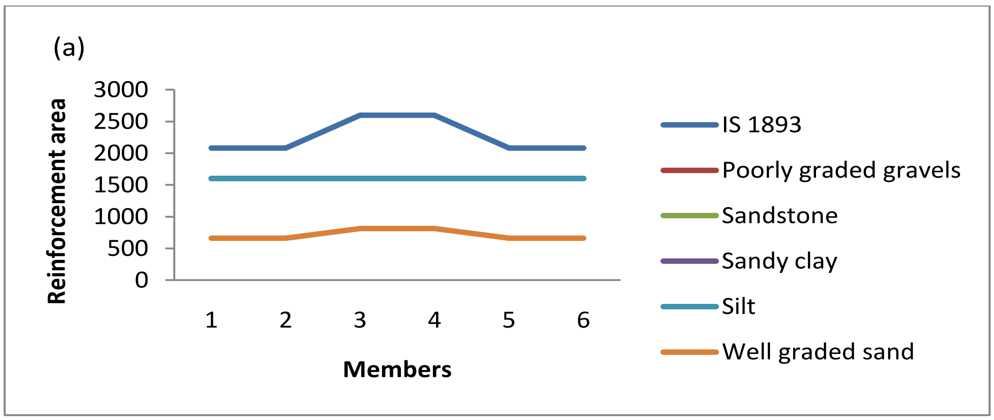


Fig. 4.19: Bending moment of column in KNm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.



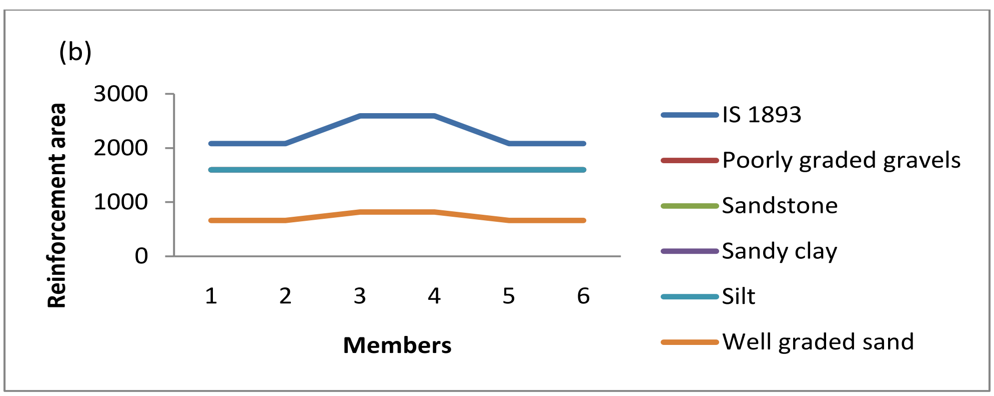


Fig. 4.20: Reinforcement area of column in mm^2 with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig 4.19 it was observed that the bending moment for column members has higher values as per IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values and the well graded sand has the least for both the direction. Also the value remains the same in both the direction of propagation. Hence the reinforcement of the columns are found to follow trend as above as shown in fig. 4.20.

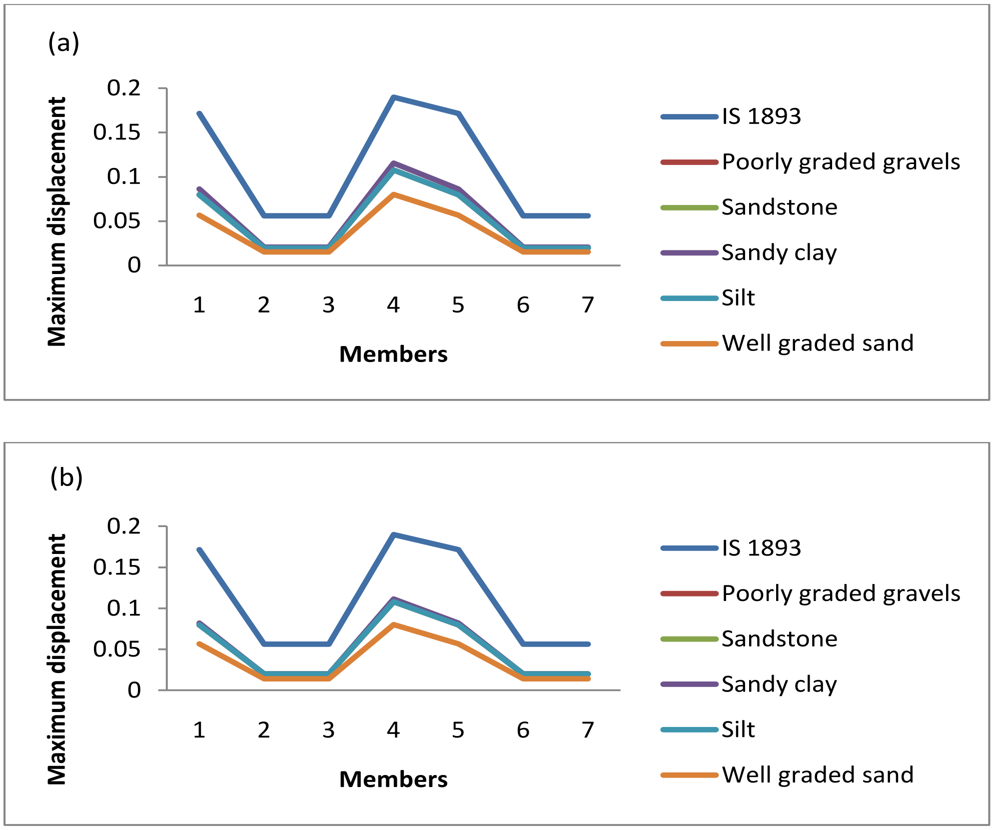
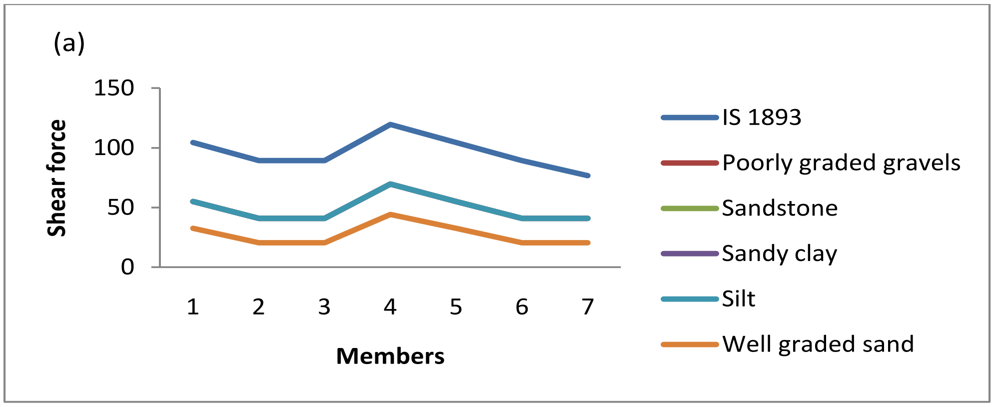


Fig. 4.21: Maximum displacement of 1st floor beams cm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.21 it was observed that the maximum displacement for 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. Sandy clay has slightly higher value in compared to poorly graded gravels, sandstone, silt and well graded sand. The poorly graded gravels, sandstone and silt has the same values and the well graded sand has the least for both the direction.



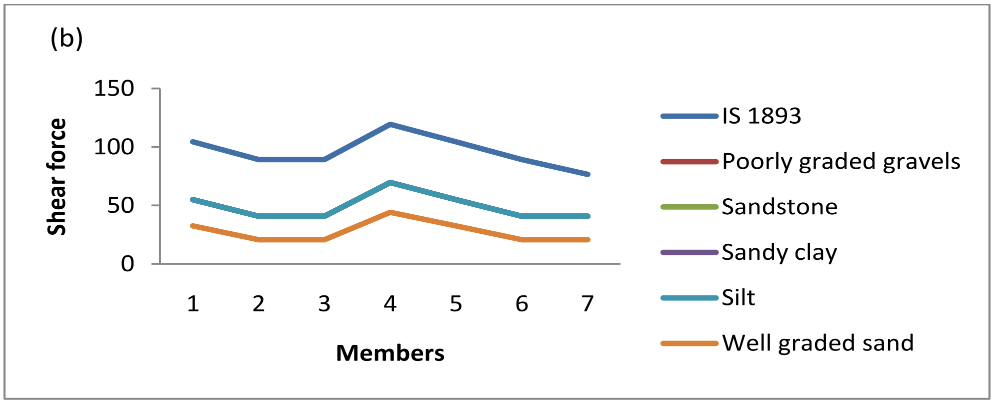
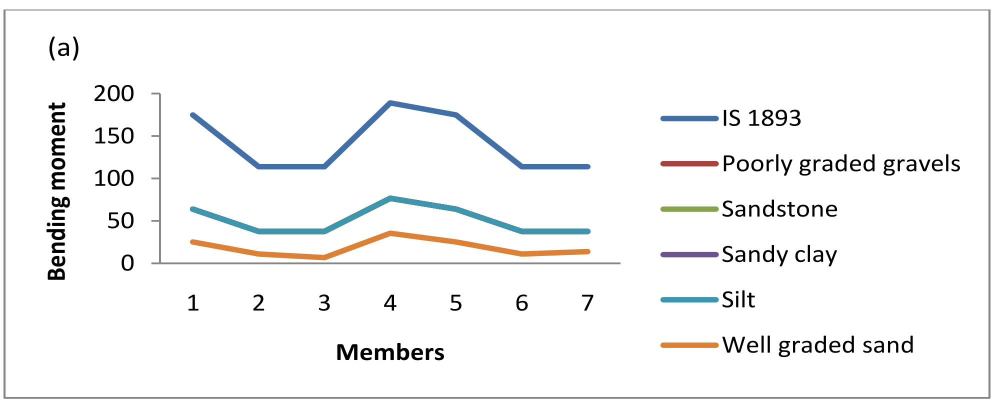


Fig. 4.22: Shear forces of 1st floor beams KN with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.22 it is observed that the shear forces in 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values and the well graded sand has the least for both the direction.



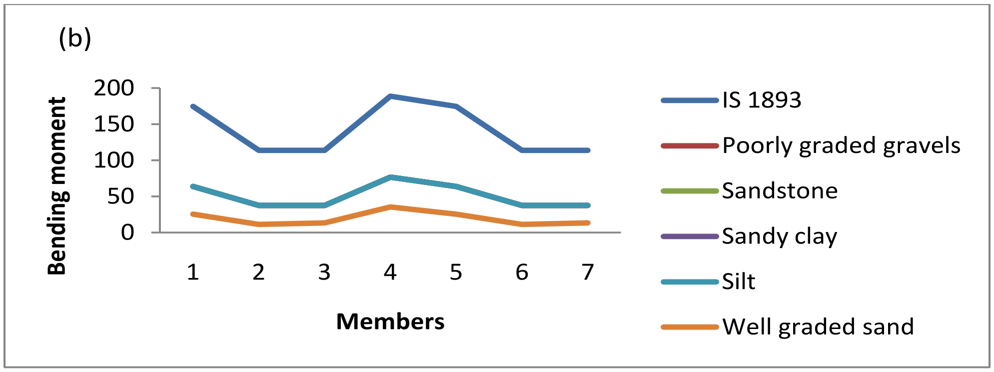
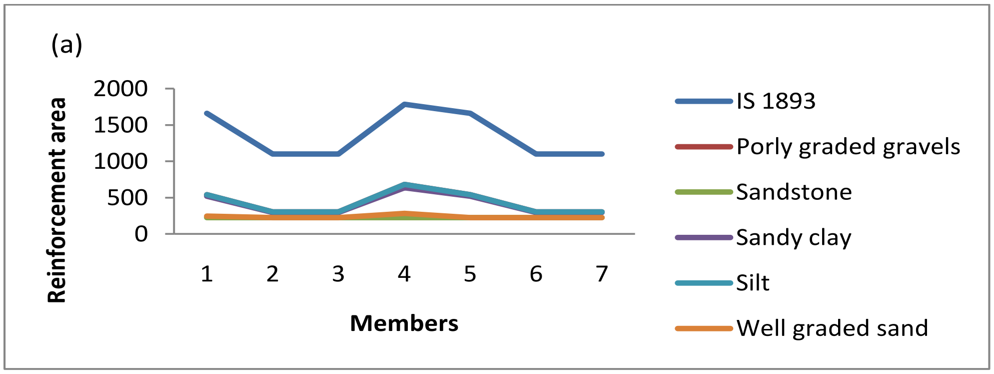
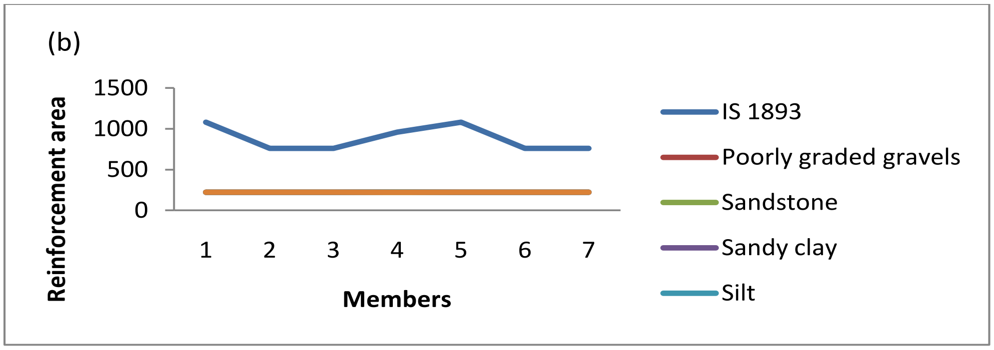
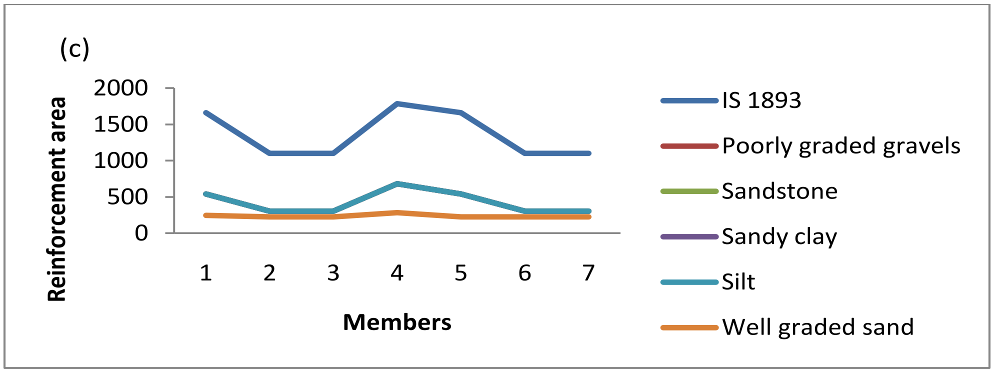


Fig. 4.23: Bending moment of 1st floor beams KNm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.23 it was observed that the bending moment for 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values and the well graded sand has the least for both the direction. In member 3 of well graded sand the bending moment value is higher in transverse direction compared to longitudinal direction and the rest values remain the same in both the direction of propagation.







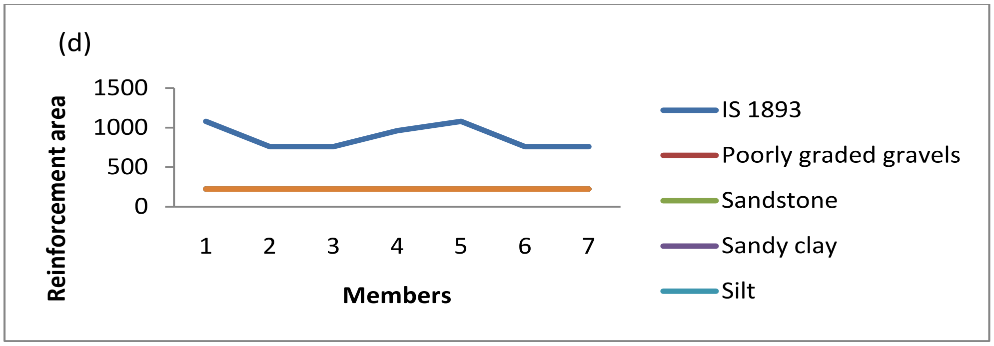


Fig. 4.24: Reinforcement area of 1st floor beams mm^2 with respect to members of the building at 0 PI a) top reinforcement in longitudinal direction b) bottom reinforcement in longitudinal c) top reinforcement in transverse direction d) bottom reinforcement in transverse direction.

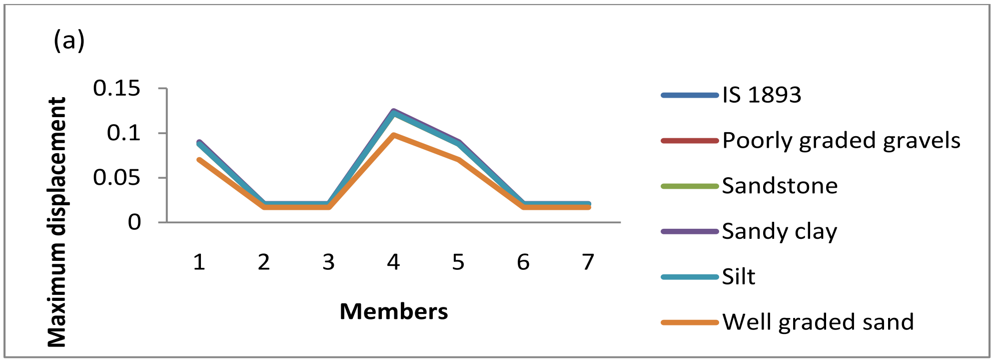
From fig. 4.24 it was observed that the reinforcement area for 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation.

In fig. 4.24 a), silt has slightly higher value for member 4 and 5 than sandy clay, both of which have higher value in compared to poorly graded gravels, sandstone and well graded sand. The poorly graded gravels, sandstone and well graded sand have uniform values except that the well graded sand has slightly higher value for member 4.

In fig. 4.24 b), the reinforcement area has uniform value for all the types of soil but have slightly higher value for the member 4. The IS 1893 design has higher value compared to all the types of soil.

In fig. 4.24 c), the reinforcement area for the IS 1893 design have the highest value and the poorly graded gravels, sandstone, sandy clay and silt have all the same value. The well graded sand has the least value of all.

In fig. 4.24 d), the reinforcement area for all the soil has uniform values.



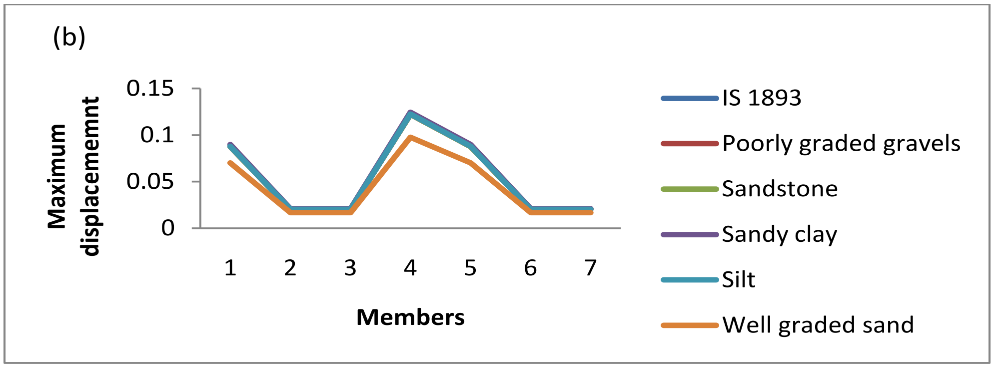
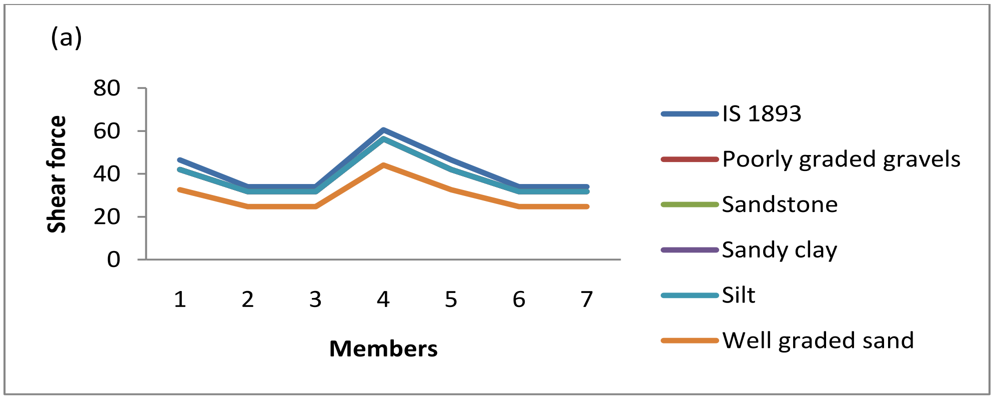


Fig. 4.25: Maximum displacement of 10^{th} floor beams in cm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.25 it was observed that the maximum displacement at 10^{th} floor, the beam members has almost same values for IS 1893 design, poorly graded gravels, sandstone, sandy clay and silt in both the direction of propagation. The well graded sand has the least value for both the direction.



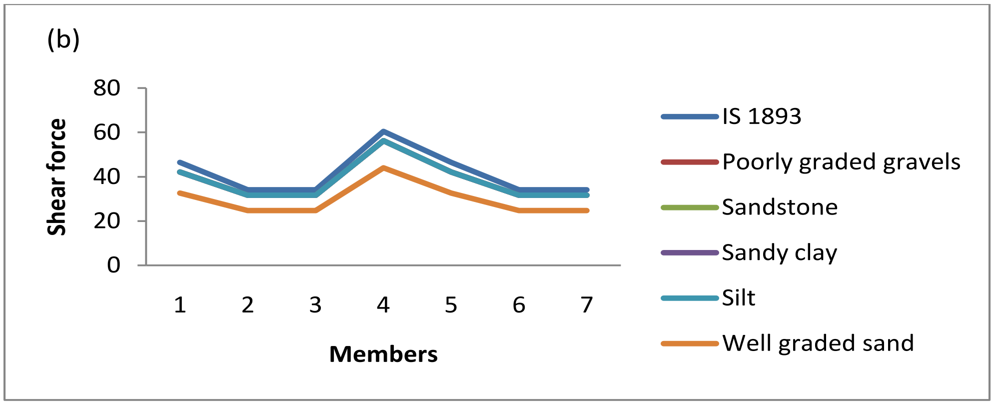


Fig. 4.26: Shear forces of 10th floor beams in KN with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.26 it was observed that the shear forces for 10th floor beams members for IS 1893 design has highest values in compared to rest of soil in both the directions and poorly graded gravels, sandstone, sandy clay and silt have same values. But the well graded sand has the least value among all.

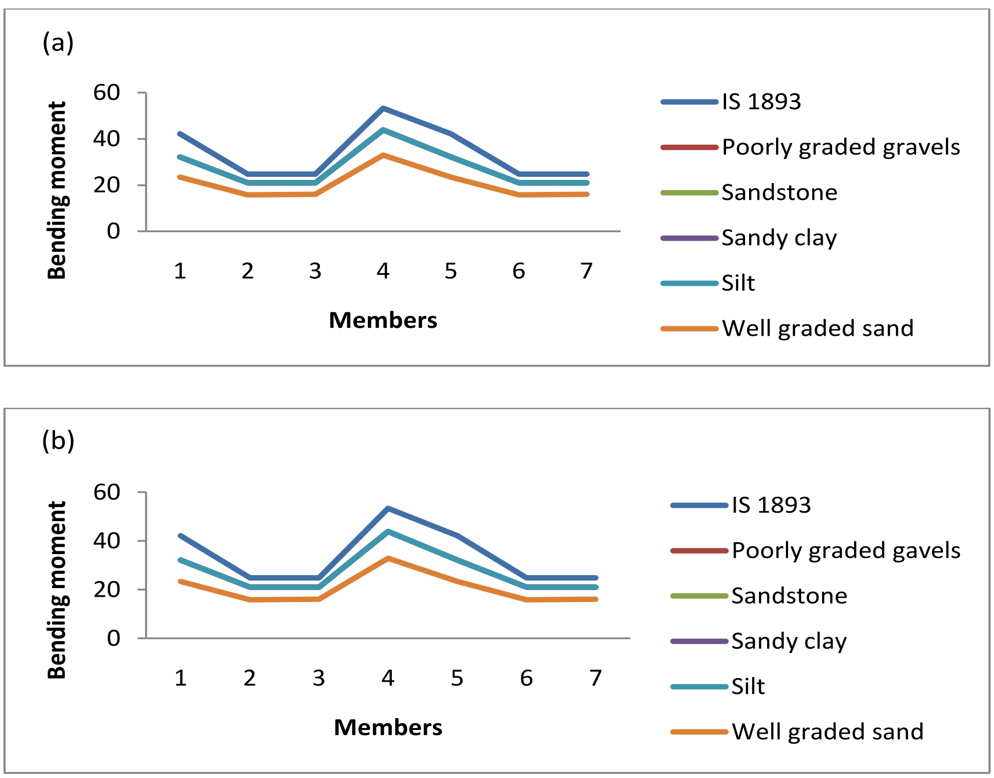
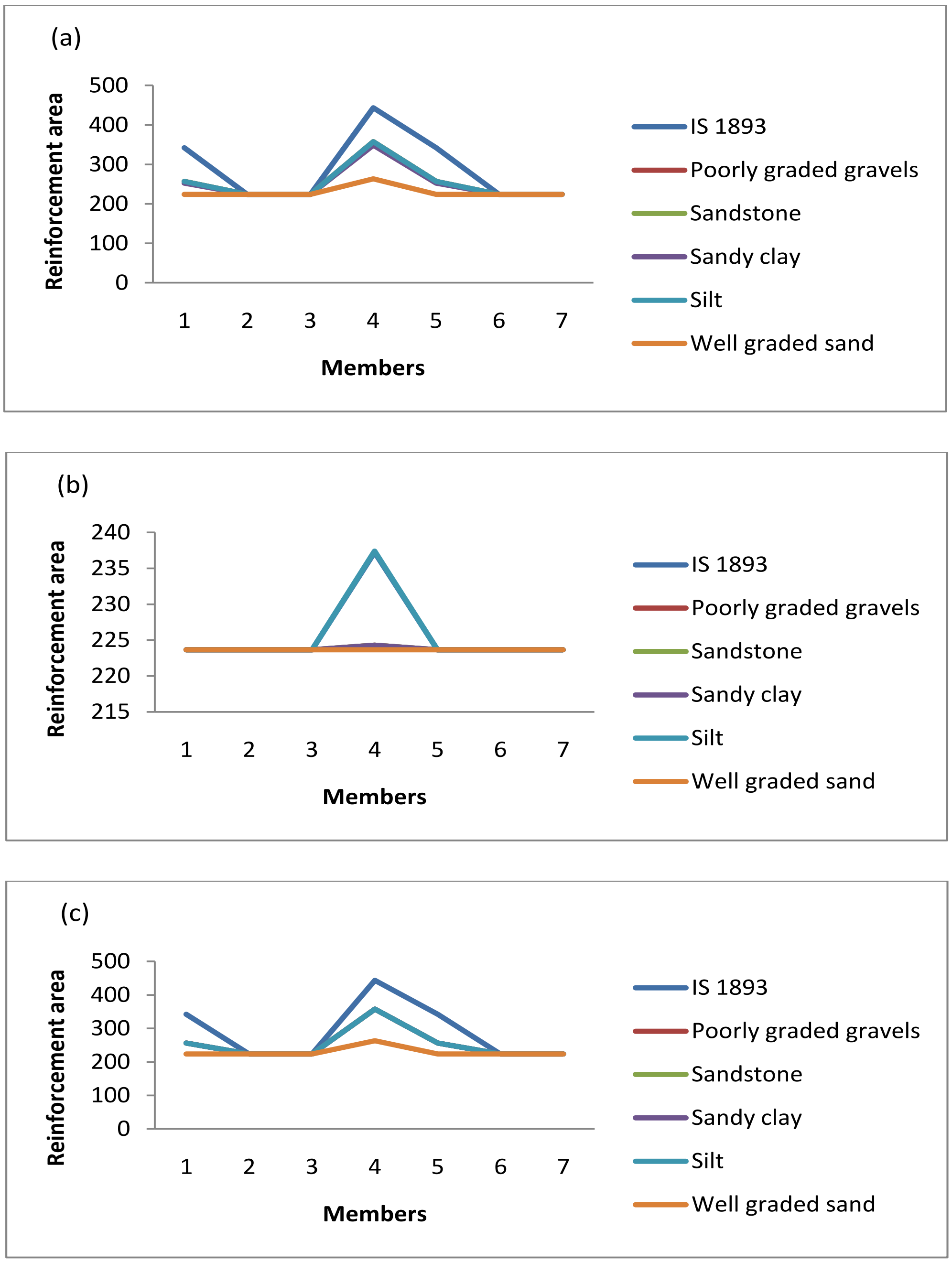


Fig. 4.27: Bending moment of 10th floor beams in KNm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.27 it was observed that the bending moment at 10th floor beams members for IS 1893 design has highest values in compared to rest of soil in both the directions and poorly graded gravels, sandstone, sandy clay and silt have same values. But the well graded sand has the least value among all.



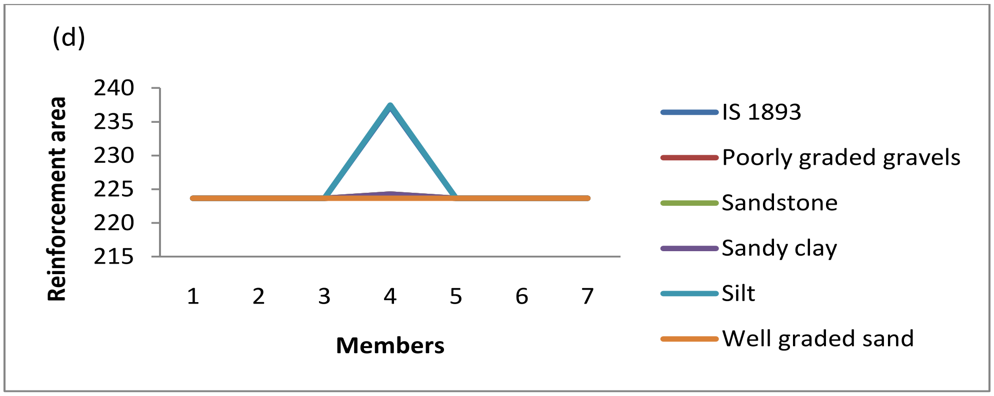


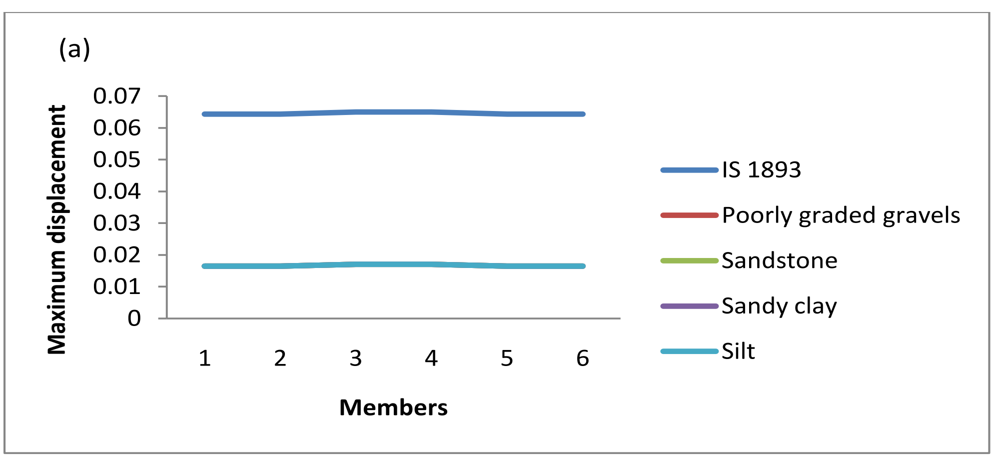
Fig. 4.28: Reinforcement area of 10th floor beams mm^2 with respect to members of the building at 0 PI a) top reinforcement in longitudinal direction b) bottom reinforcement in longitudinal c) top reinforcement in transverse direction d) bottom reinforcement in transverse direction.

In fig. 4.28 a), IS 1893 has highest value but for member 2, 3, 6 and 7 there values are same for all the types of soil. Well graded sand has least value.

In fig. 4.28 b), the reinforcement area has uniform value for all the types of soil except for member 4 of silt and sandy clay.

In fig. 4.28 c), IS 1893 has highest value but for member 2, 3, 6 and 7 there values are same for all the types of soil. Well graded sand has least value.

In fig. 4.28 d), the reinforcement area has uniform value for all the types of soil except for member 4 of silt and sandy clay.



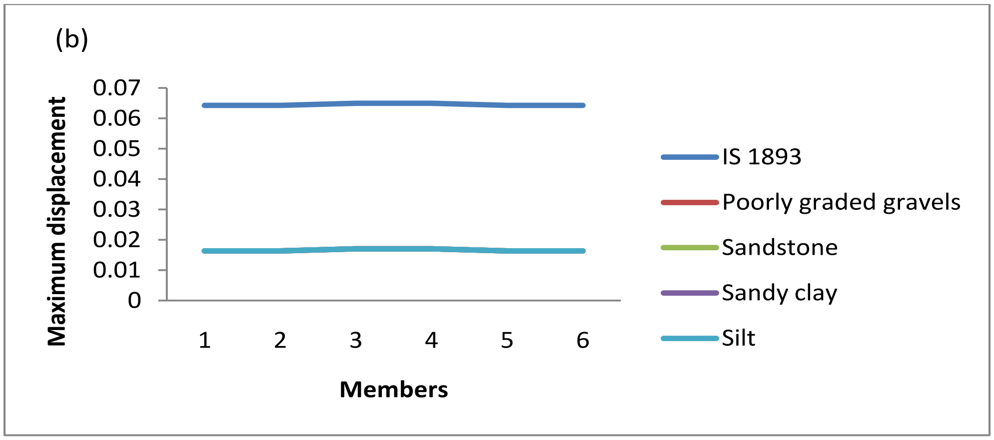
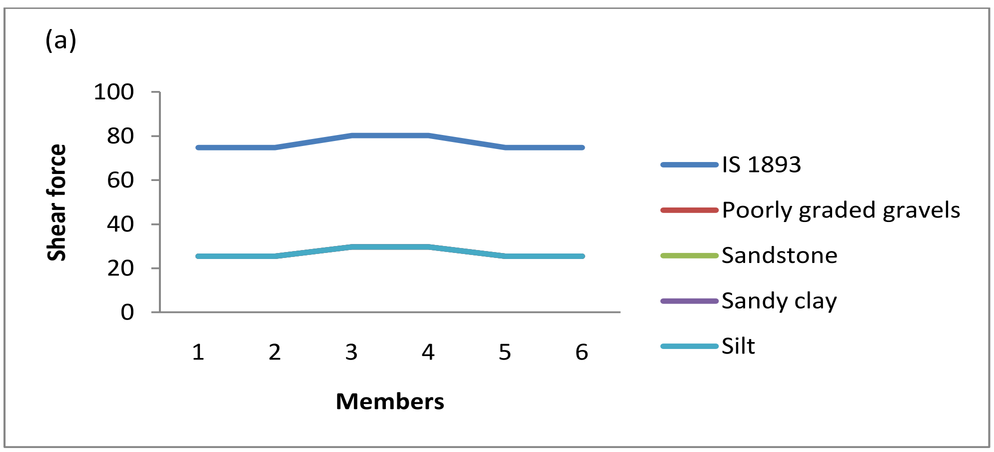


Fig. 4.29: Maximum displacements of column in cm with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.29 it was observed that the maximum displacement fro IS 1893 design has higher displacement in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same displacement values.



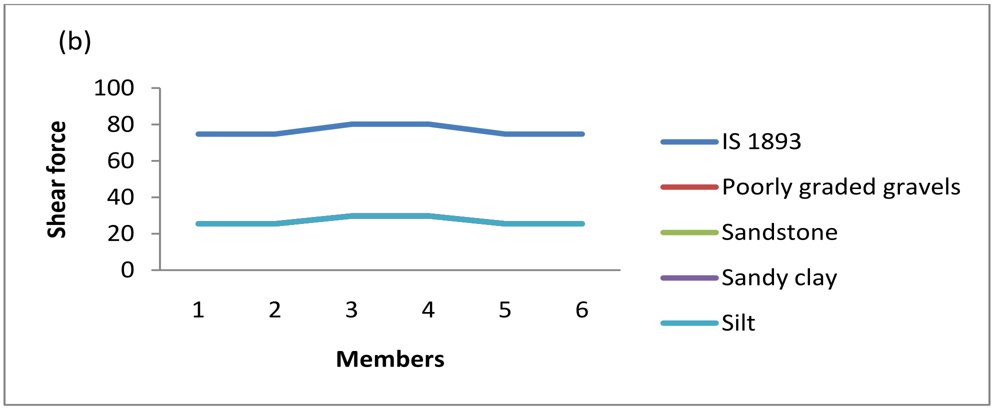
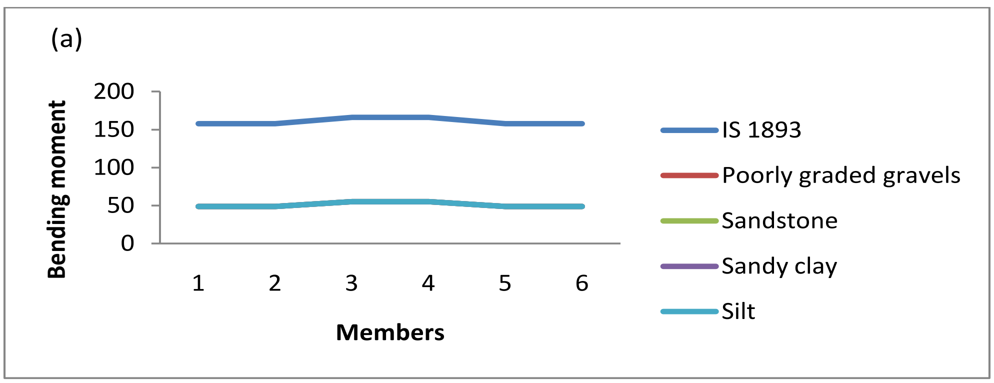


Fig. 4.30: Shear forces of column in KN with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.30 it was observed that the shear forces for column members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values.



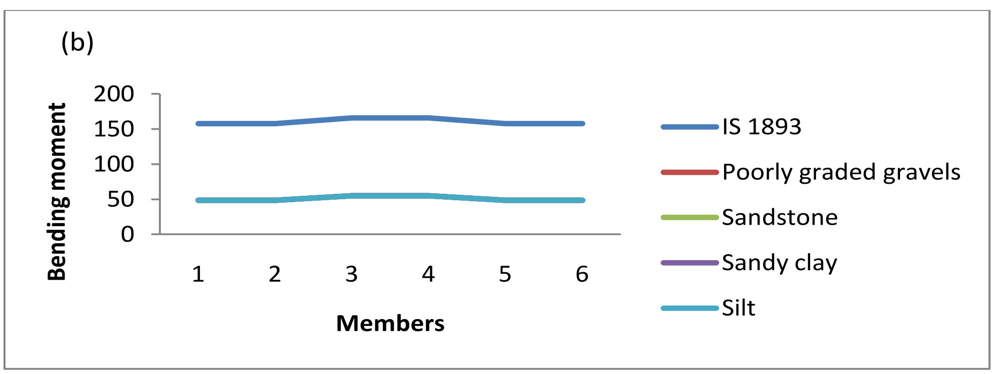
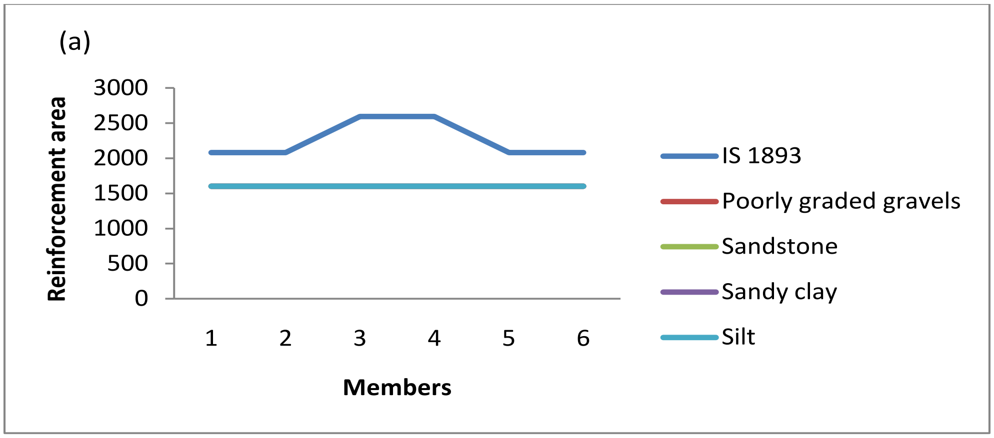


Fig. 4.31: Bending moment of column in KNm with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.31 it was observed that the bending moment for column members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same uniform values.



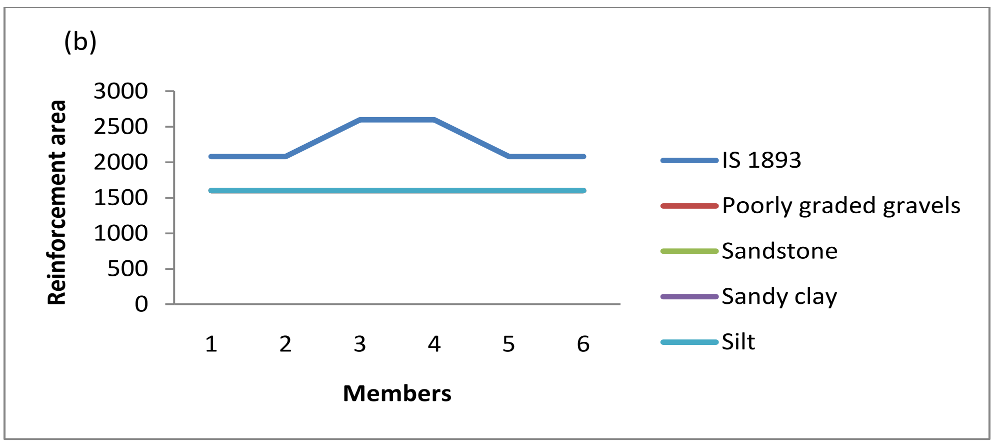
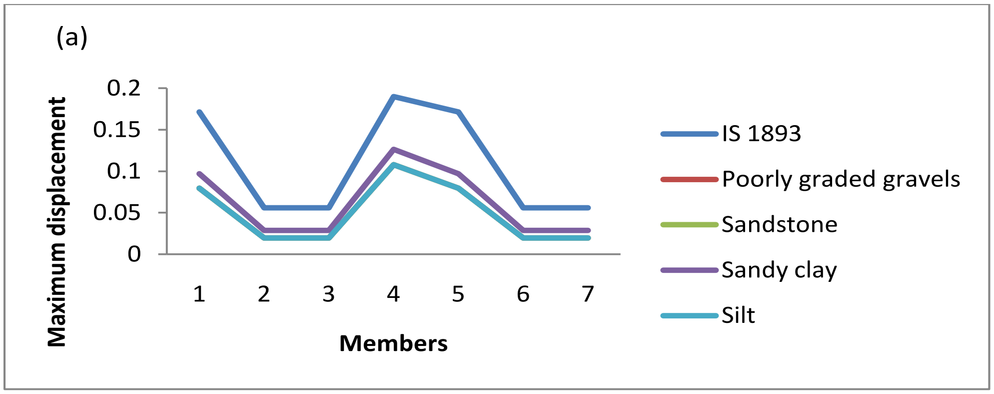


Fig. 4.32: Reinforcement area of column in mm^2 with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.32 it was observed that the bending moment for column members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values and it is uniform in nature.



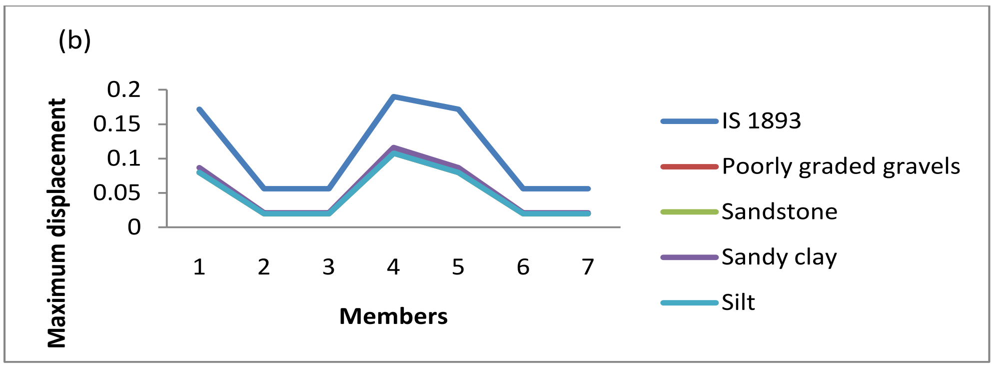
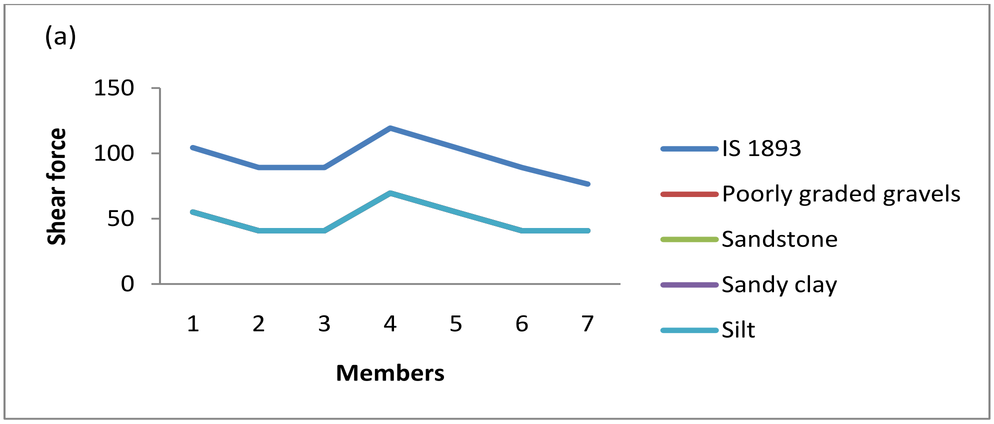


Fig. 4.33: Maximum displacement of 1st floor beams cm with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.33 it was observed that the maximum displacement for 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. Sandy clay has higher value in compared to poorly graded gravels, sandstone, silt and well graded sand also the value in longitudinal direction is higher than in transverse direction. The poorly graded gravels, sandstone and silt has the same values. Also the value remains the same in both the direction of propagation for IS 1893 design, poorly graded gravels, sandstone and silt.



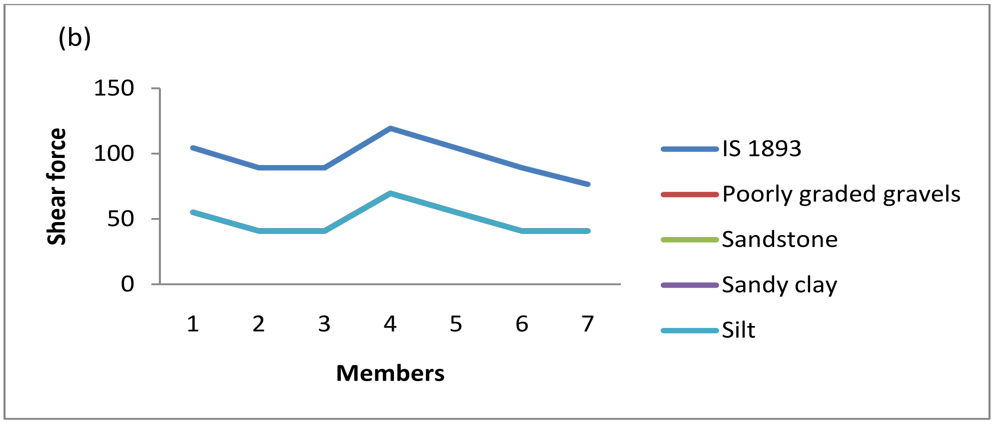
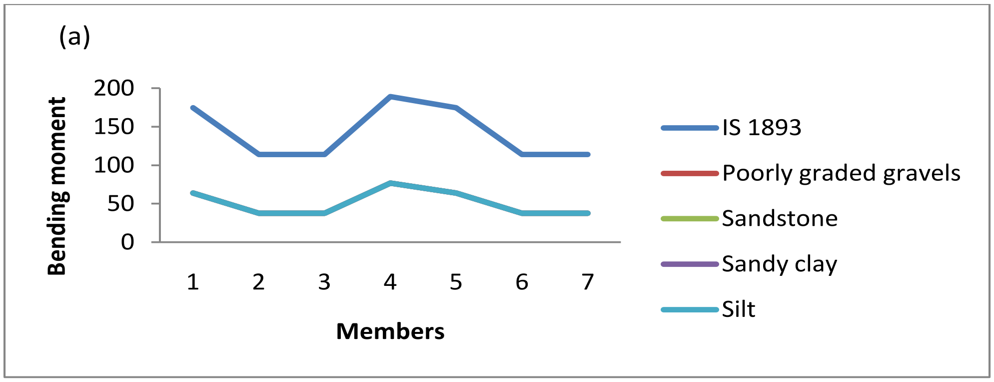


Fig. 4.34: Shear forces of 1st floor beams KN with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.34 it was observed that the shear forces in 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values.



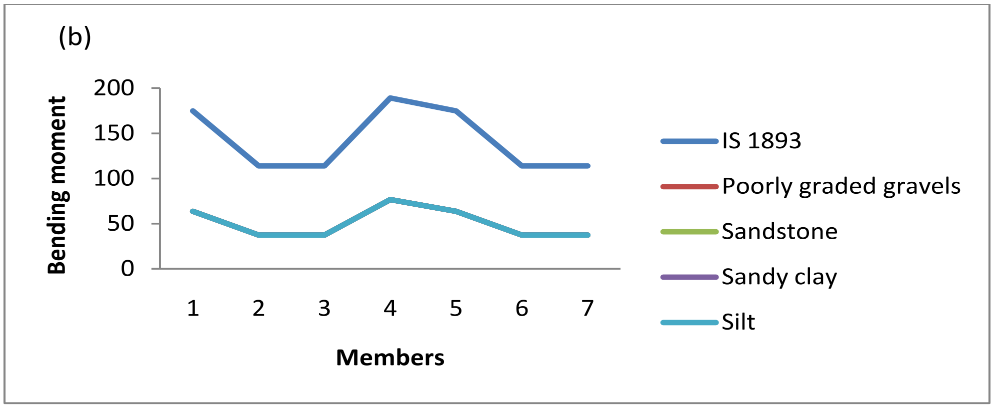
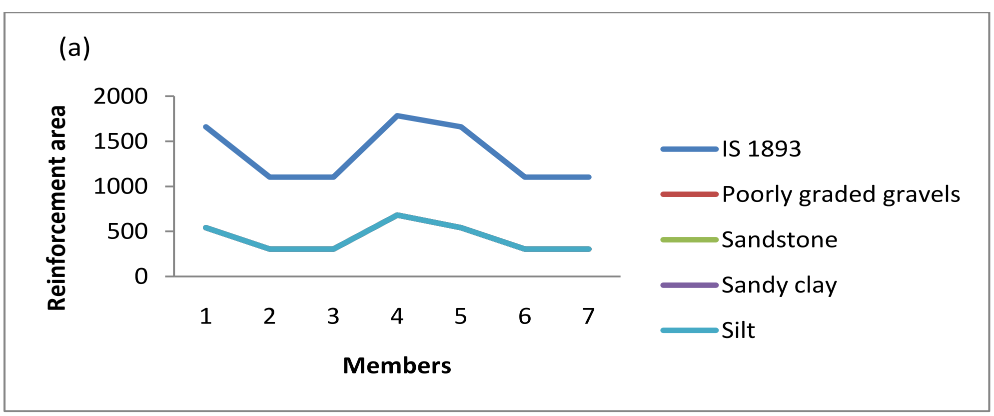
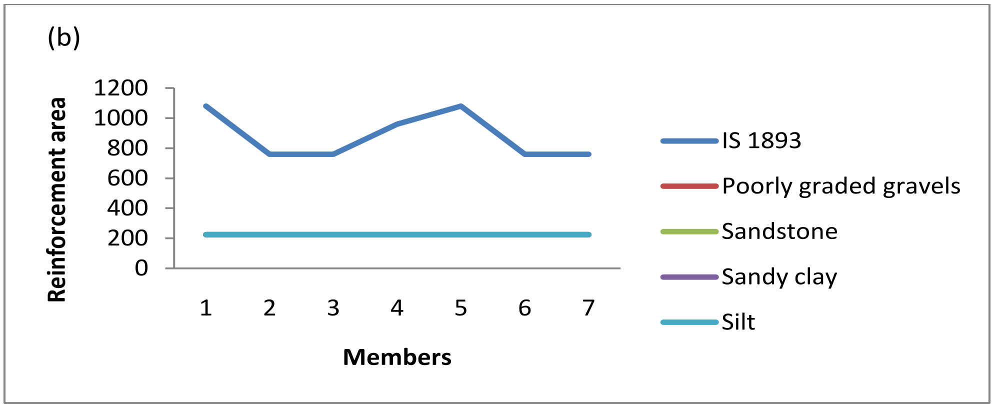
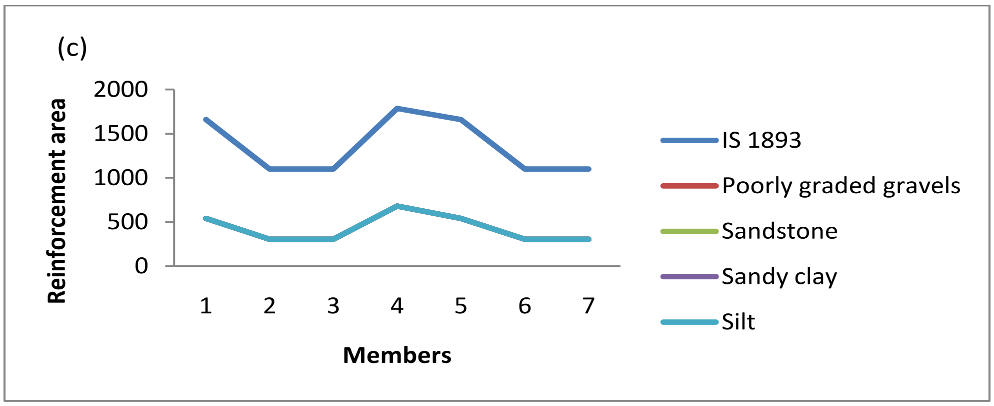


Fig. 4.35: Bending moment of 1st floor beams KNm with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.35 it was observed that the bending moment for 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values.







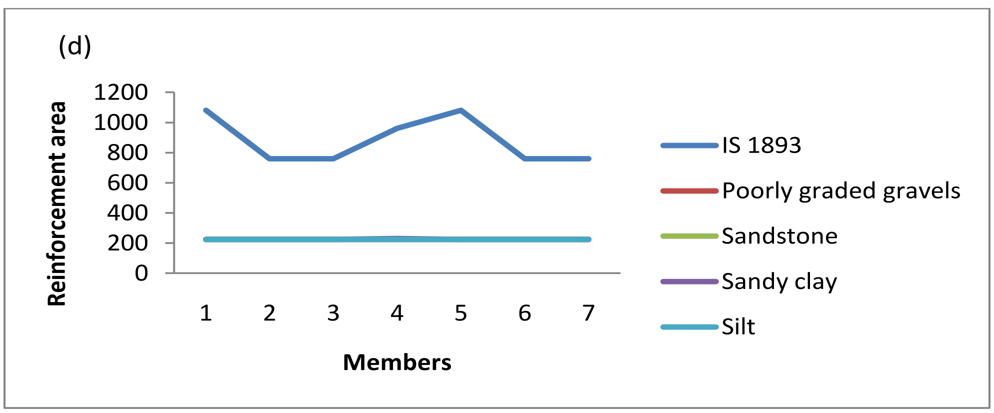


Fig. 4.36: Reinforcement area of 1st floor beams mm^2 with respect to members of the building at 30 PI a) top reinforcement in longitudinal direction b) bottom reinforcement in longitudinal c) top reinforcement in transverse direction d) bottom reinforcement in transverse direction.

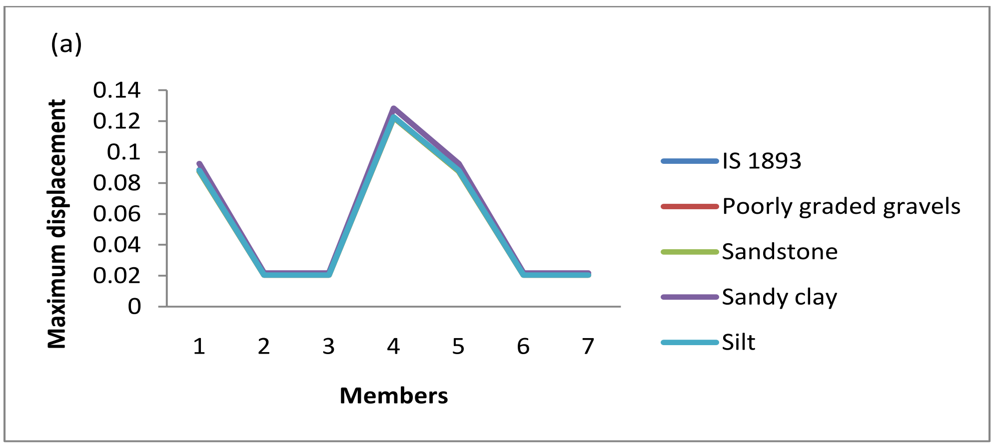
From fig. 4.36 it was observed that the reinforcement area for 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation but has different value for all the direction.

In fig. 4.36 a), the values for poorly graded gravels, sandstone, sandy clay and silt is same.

In fig. 4.36 b), the values for poorly graded gravels, sandstone, sandy clay and silt is uniform.

In fig. 4.36 c), the values for poorly graded gravels, sandstone, sandy clay and silt is same.

In fig. 4.36 d), the values for poorly graded gravels, sandstone, sandy clay and silt is uniform but slightly higher in member 4 for sandy clay.



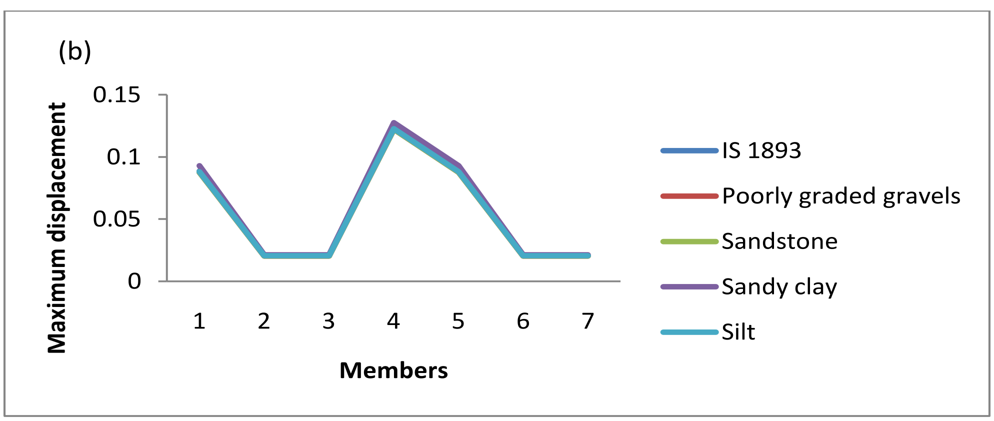


Fig. 4.37: Maximum displacement of 10th floor beams in cm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.37 it was observed that the maximum displacement at 10th floor, the beam members has almost same values for IS 1893 design, poorly graded gravels, sandstone, sandy clay and silt in both the direction of propagation.

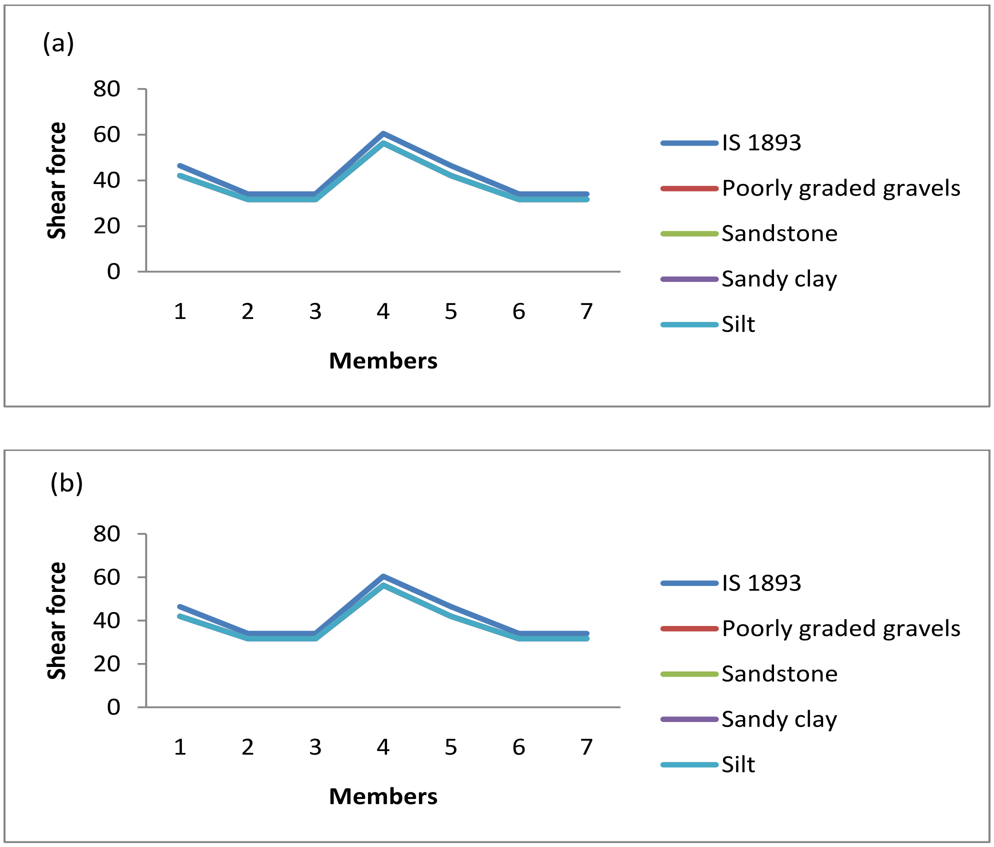
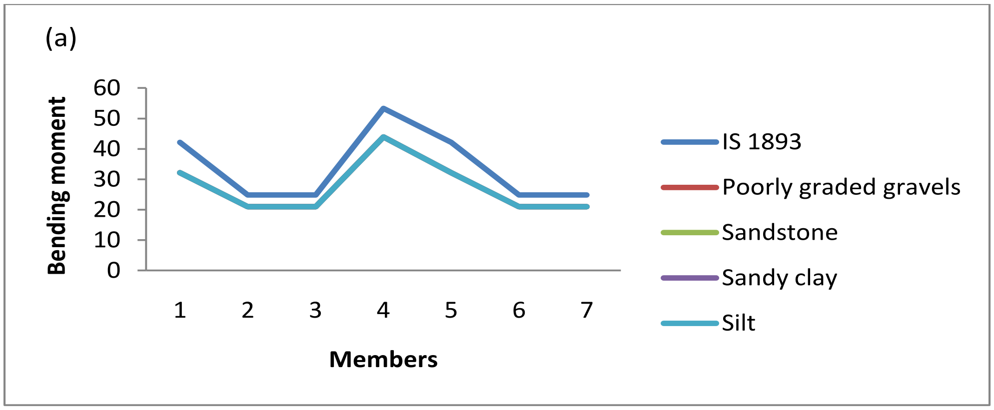


Fig. 4.38: Shear forces of 10th floor beams in KN with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.38 it was observed that the shear forces for 10th floor beams members for IS 1893 design has highest values in compared to rest of soil in both the directions and poorly graded gravels, sandstone, sandy clay and silt have same values.



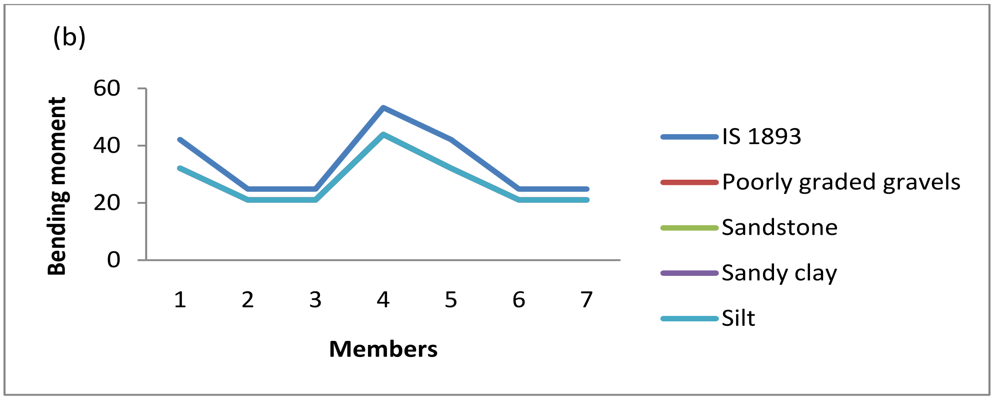
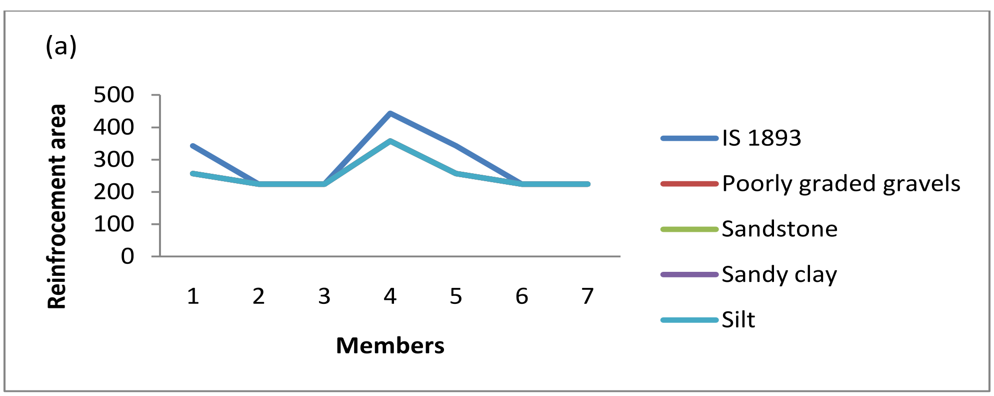


Fig. 4.39: Bending moment of 10th floor beams in KNm with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.39 it was observed that the bending moment at 10th floor beams members for IS 1893 design has highest values in compared to rest of soil in both the directions and poorly graded gravels, sandstone, sandy clay and silt have same values.



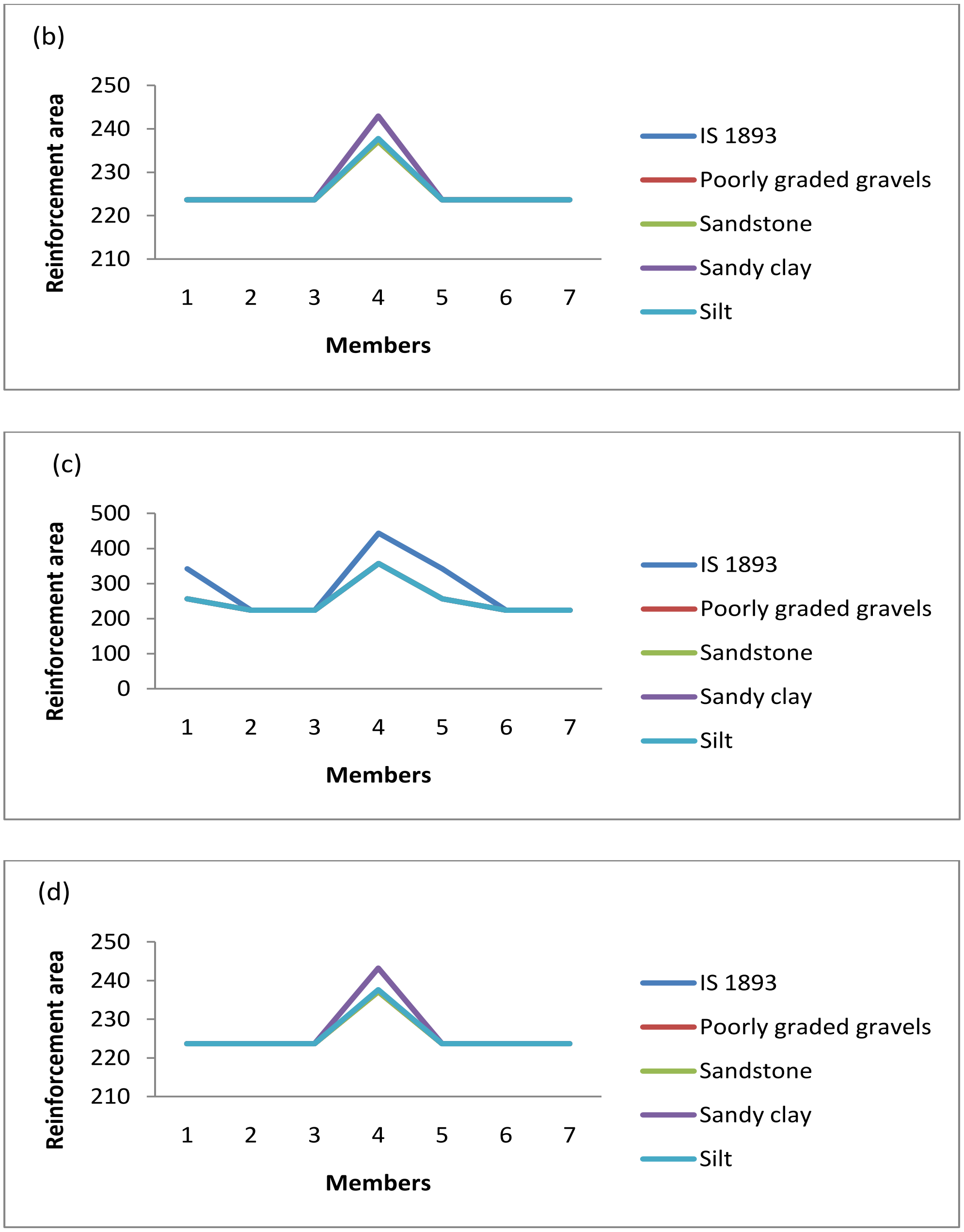


Fig. 4.40: Reinforcement area of 10th floor beams mm^2 with respect to members of the building at 30 PI a) top reinforcement in longitudinal direction b) bottom reinforcement in longitudinal c) top reinforcement in transverse direction d) bottom reinforcement in transverse direction.

In fig. 4.40 a), IS 1893 has highest value but for member 2, 3, 6 and 7 there values are same for all the types of soil. Well graded sand has least value.

In fig. 4.40 b), the reinforcement area has same value for all the types of soil except for member 4 of sandy clay and sandstone. Sandstone has lesser value for member 4 compare to others.

In fig. 4.40 c), IS 1893 has highest value but for member 2, 3, 6 and 7 there values are same for all the types of soil.

In fig. 4.40 d), the reinforcement area has same value for all the types of soil except for member 4 of sandy clay and sandstone. Sandstone has lesser value for member 4 compare to others.

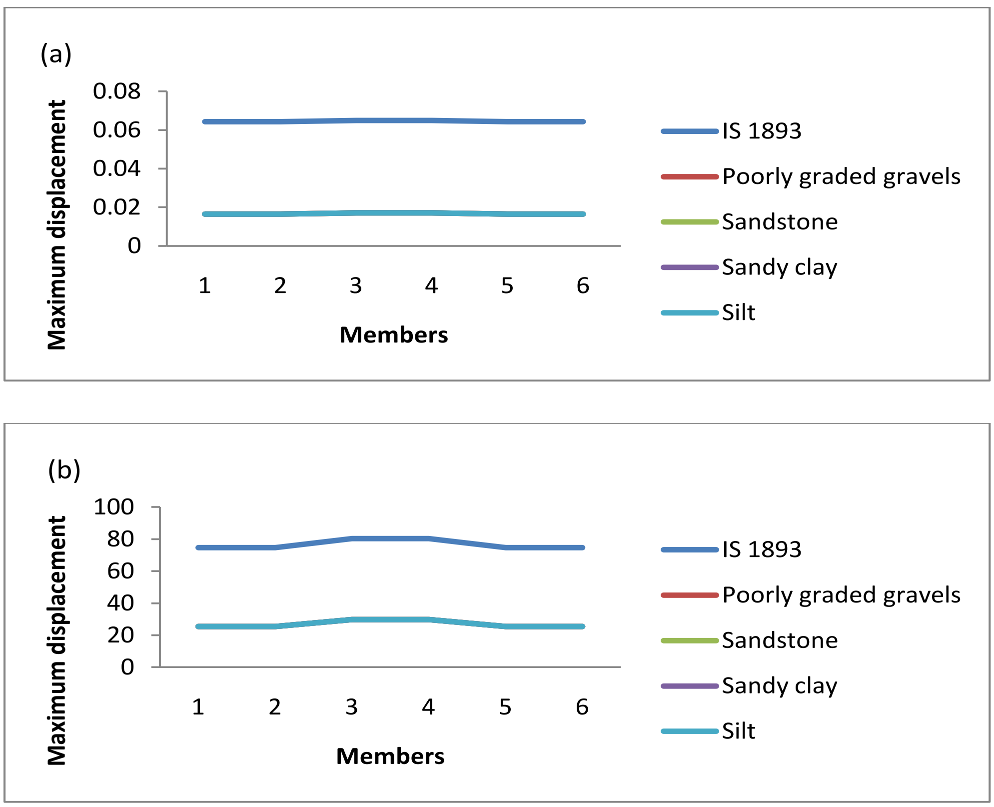


Fig. 4.41: Maximum displacements of column in cm with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.41 it was observed that the maximum displacement fro IS 1893 design has higher displacement in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same displacement values.

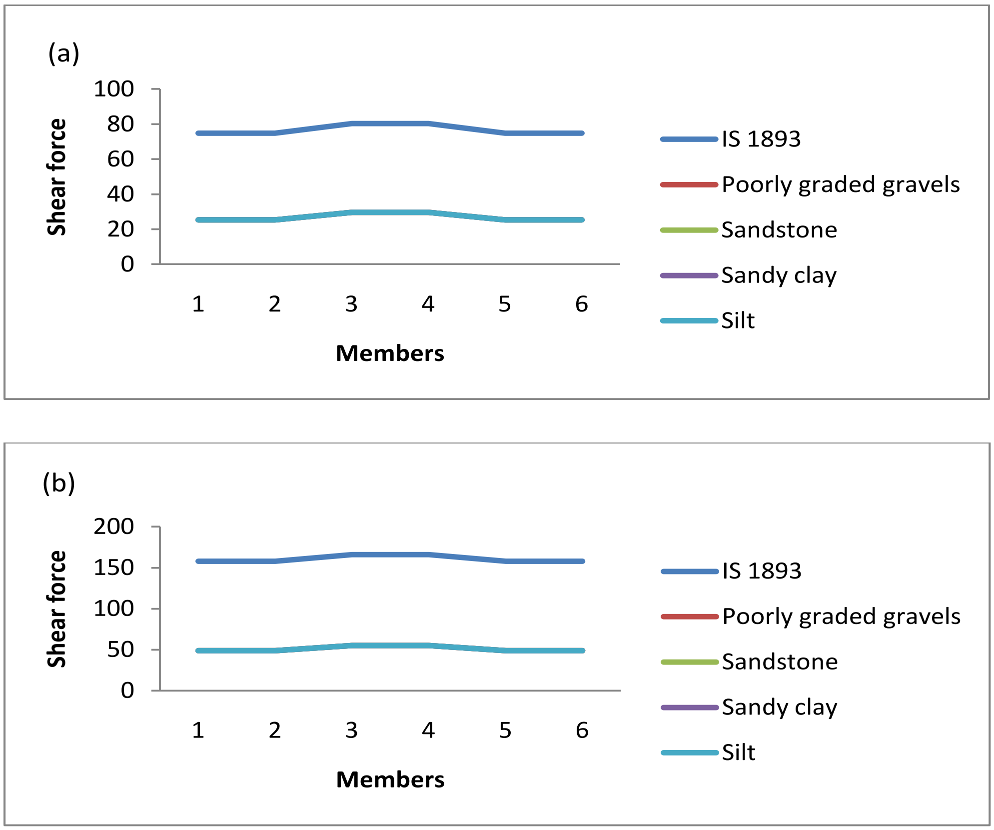
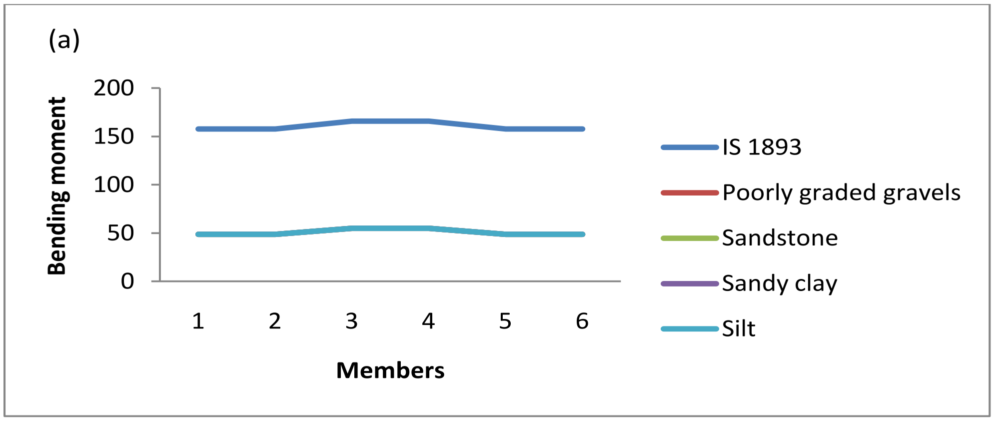


Fig. 4.42: Shear forces of column in KN with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.42 we find that the shear forces for column members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same.



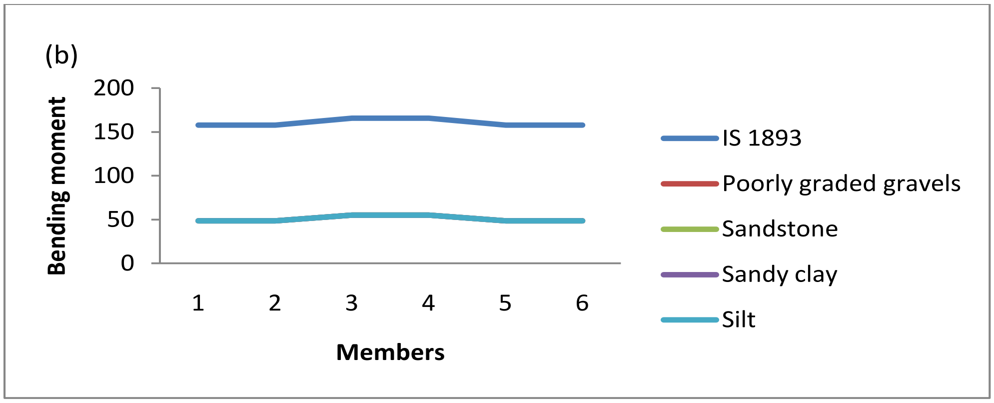
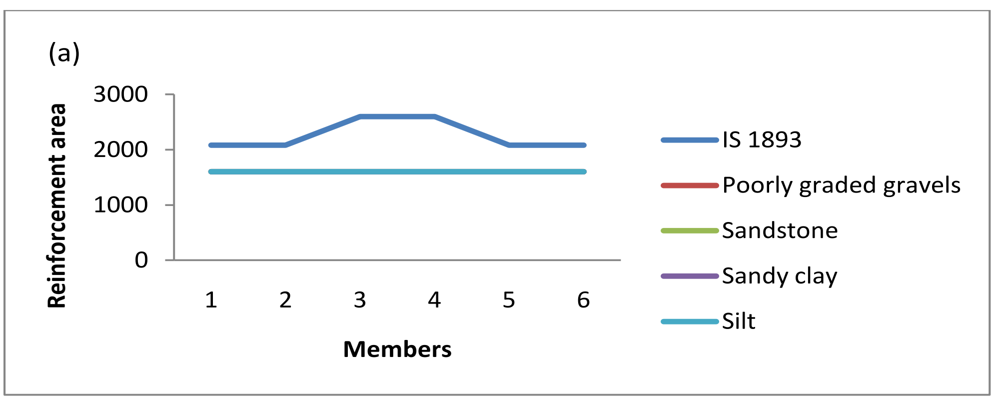


Fig. 4.43: Bending moment of column in KNm with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. It was observed that the bending moment for column members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values.



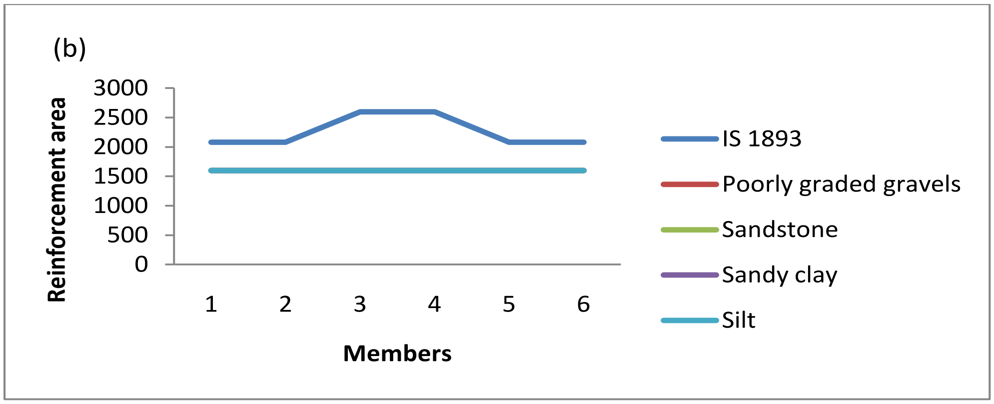
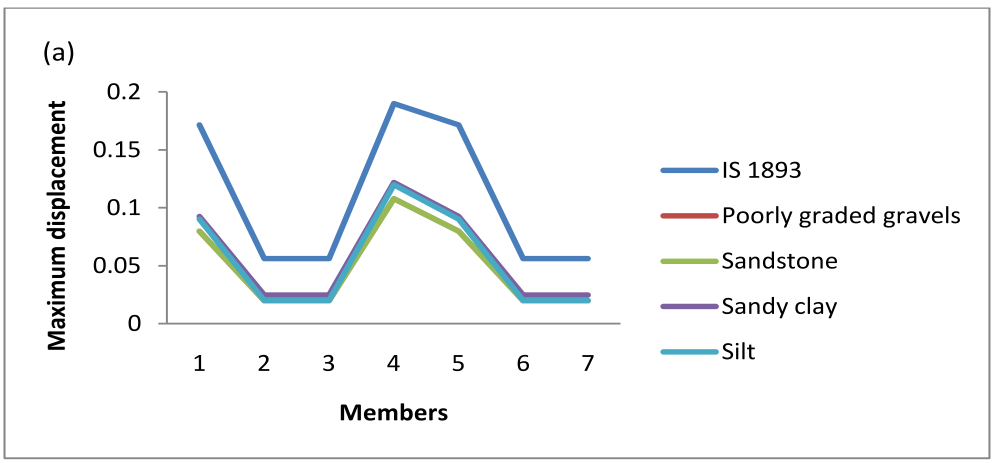


Fig. 4.44: Reinforcement area of column in mm^2 with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.44 it was observed that the bending moment for column members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values and it is uniform in nature.



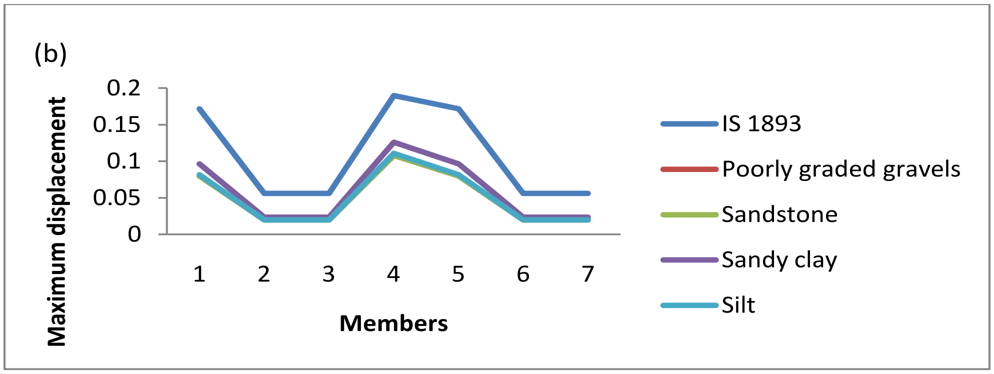
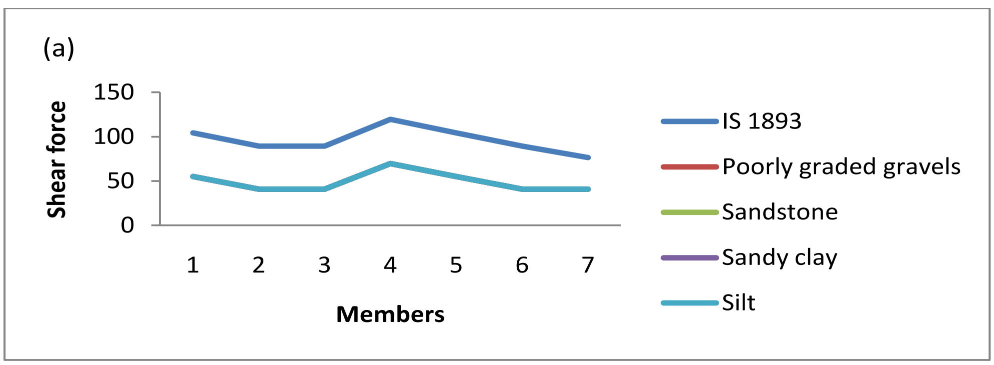


Fig. 4.45: Maximum displacement of 1st floor beams cm with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.45 we find that the maximum displacement for 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. Sandy clay has slightly higher value in compared to poorly graded gravels, sandstone and silt. In a) poorly graded gravels and sandstone has the lowest value and in b) it is almost same with silt.



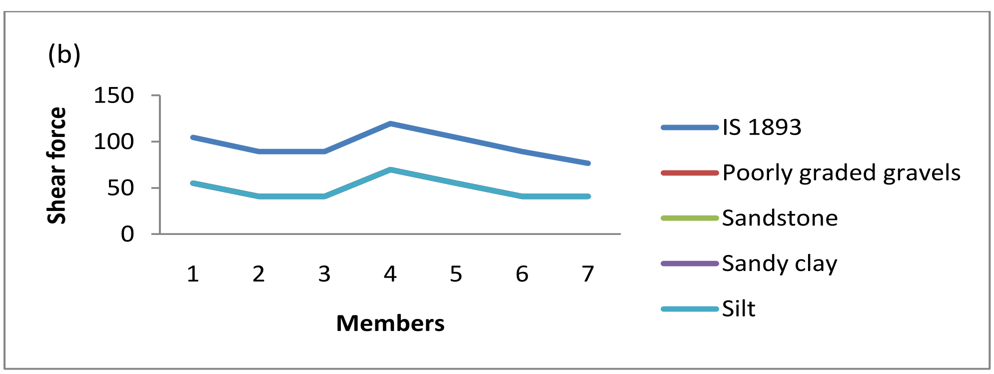
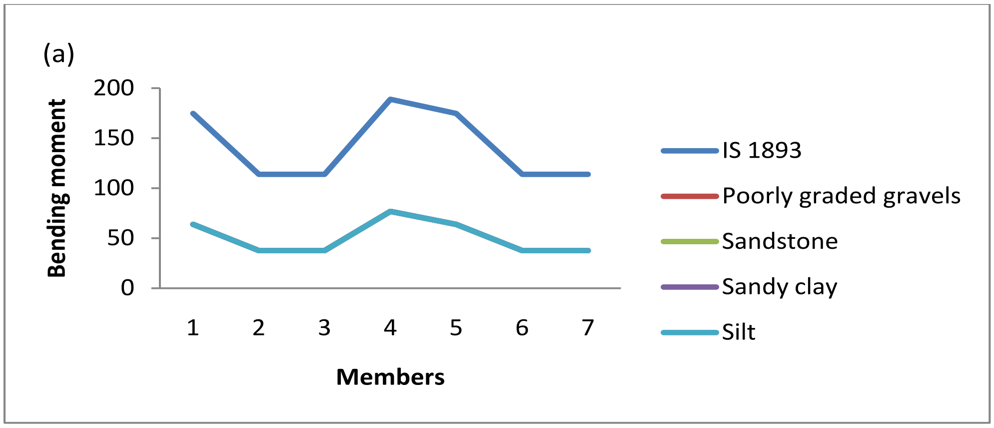


Fig. 4.46: Shear forces of 1st floor beams KN with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.46 it was observed that the shear forces in 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values.



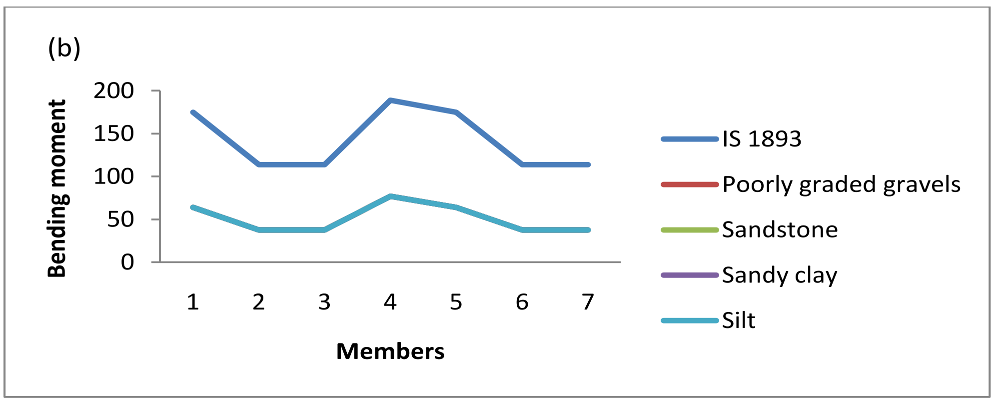
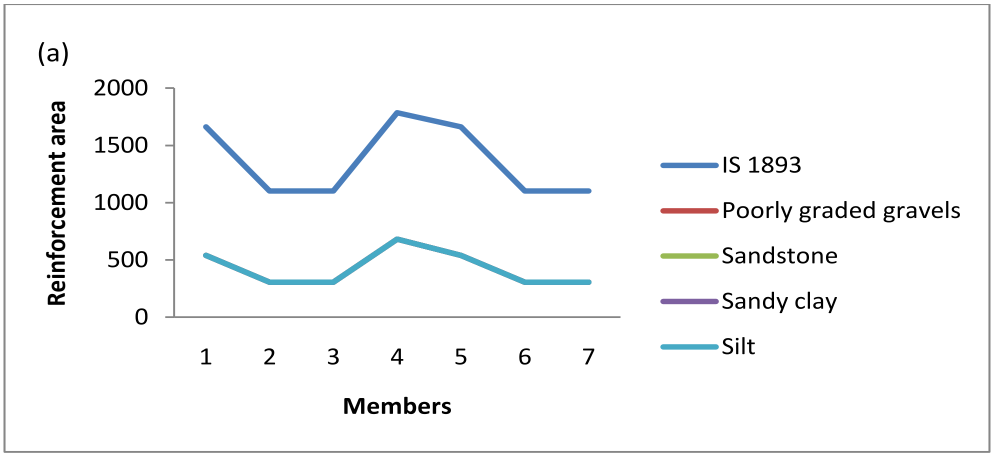
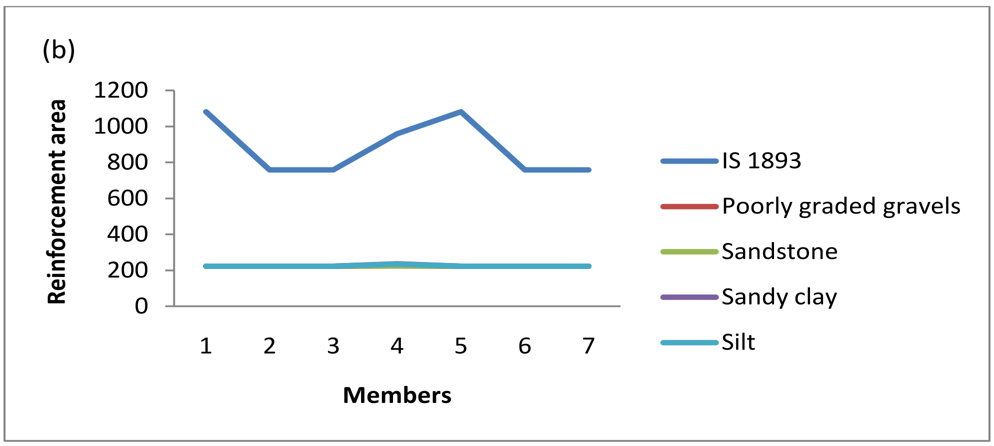
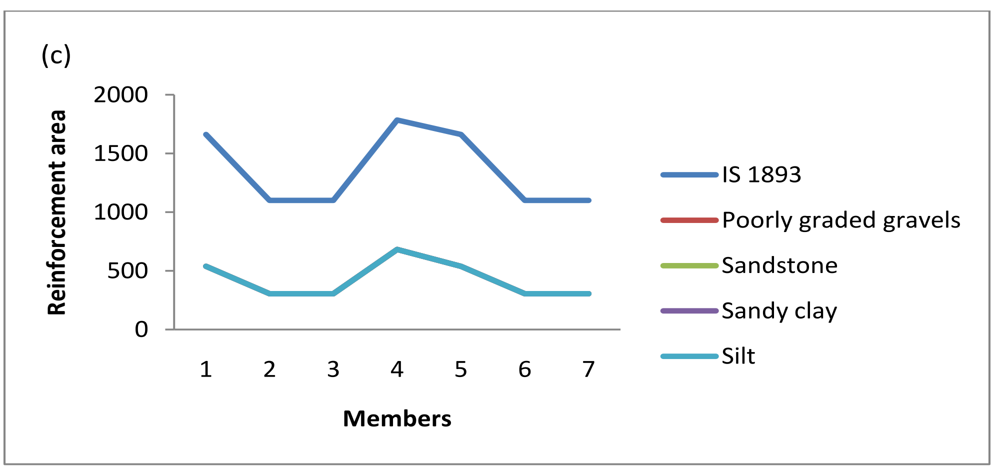


Fig. 4.47: Bending moment of 1st floor beams KNm with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.47 it was observed that the bending moment for 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values.


(a)
Reinforcement area
2000
1500
1000
500
0
1
2
3
4
5
6
7
Members
IS 1893
Poorly graded gravels
Sandstone
Sandy clay
Silt


(b)
Reinforcement area
1200
1000
800
600
400
200
0
1
2
3
4
5
6
7
Members
IS 1893
Poorly graded gravels
Sandstone
Sandy clay
Silt


(c)
Reinforcement area
2000
1500
1000
500
0
1
2
3
4
5
6
7
Members
IS 1893
Poorly graded gravels
Sandstone
Sandy clay
Silt

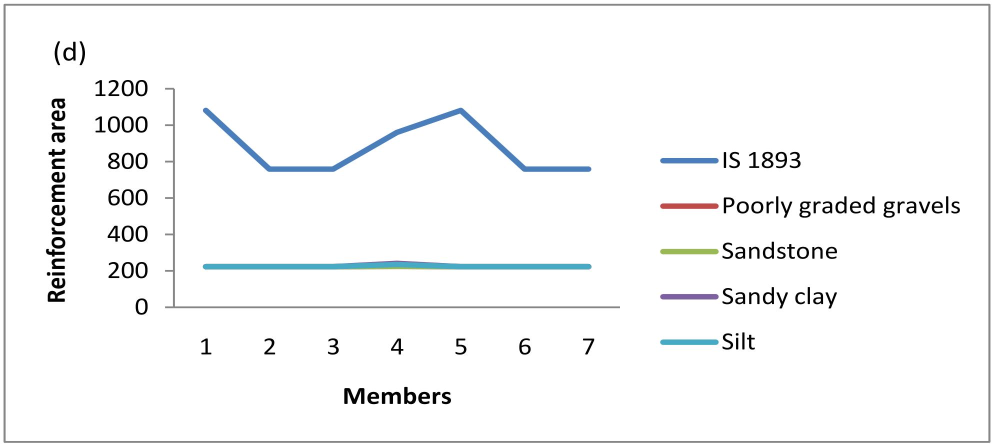


Fig. 4.48: Reinforcement area of 1st floor beams mm^2 with respect to members of the building at 200 PI a) top reinforcement in longitudinal direction b) bottom reinforcement in longitudinal c) top reinforcement in transverse direction d) bottom reinforcement in transverse direction.

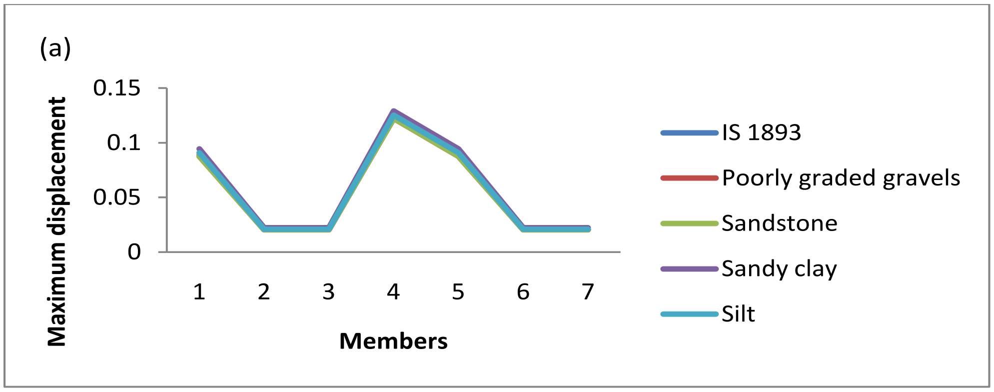
From fig. 4.48 it was observed that the reinforcement area for 1st floor beam members has higher values for IS 1893 design in compared to all the other types of soil in both the direction of seismic wave propagation but has different value for all the direction.

In fig. 4.48 a), the values for poorly graded gravels, sandstone, sandy clay and silt is same.

In fig. 4.48 b), the values for poorly graded gravels, sandstone, sandy clay and silt is uniform but sandy clay and silt has slightly higher value for member 4.

In fig. 4.48 c), the values for poorly graded gravels, sandstone, sandy clay and silt is same.

In fig. 4.48 d), the values for poorly graded gravels, sandstone, sandy clay and silt is uniform but slightly higher in member 4 for sandy clay.



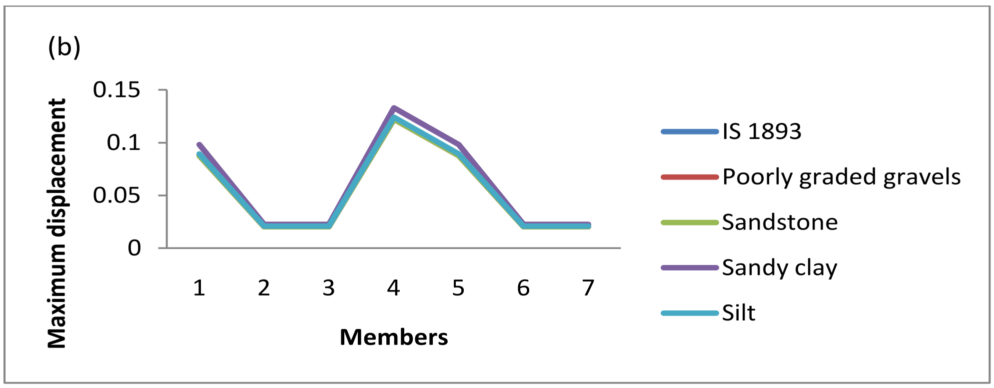
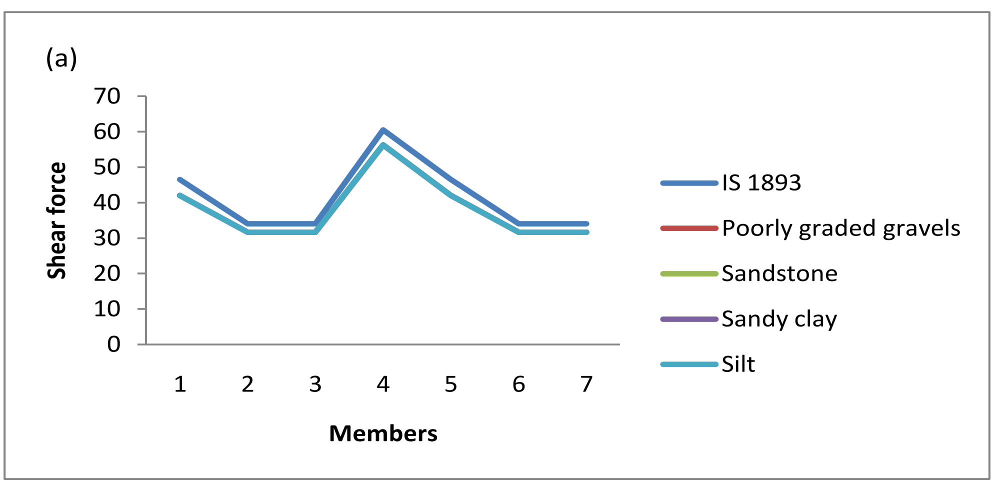


Fig. 4.49: Maximum displacement of 10th floor beams in cm with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.49 it was observed that the maximum displacement at 10th floor, the beam members has almost same values for IS 1893 design, poorly graded gravels, sandstone, sandy clay and silt in both the direction of propagation. Sandy clay has higher value for transverse direction.



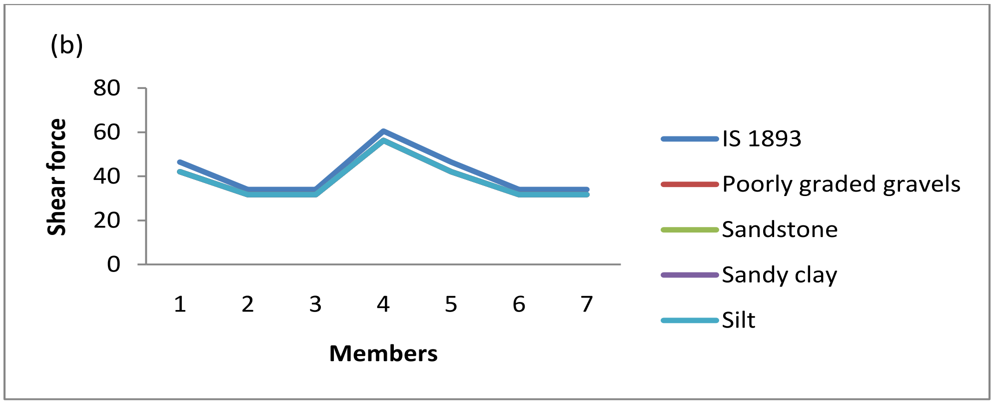
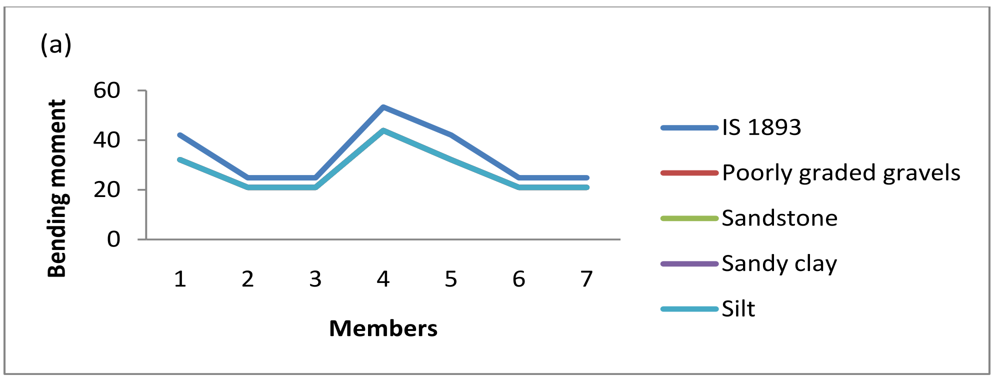


Fig. 4.50: Shear forces of 10th floor beams in KN with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.50 it was observed that the shear forces for 10th floor beams members for IS 1893 design has highest values in compared to rest of soil in both the directions and poorly graded gravels, sandstone, sandy clay and silt have same values.



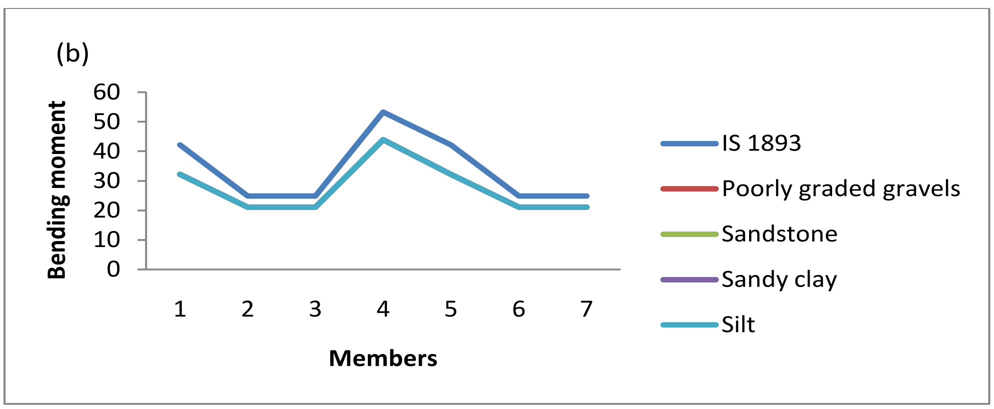
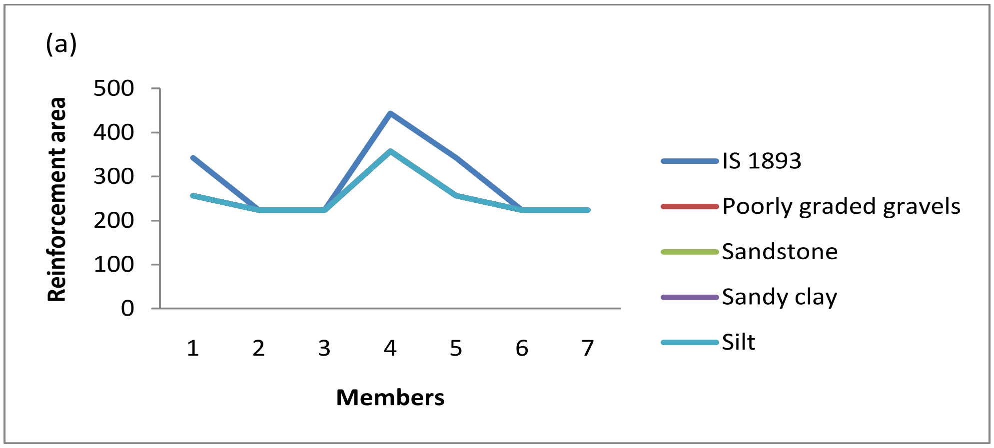
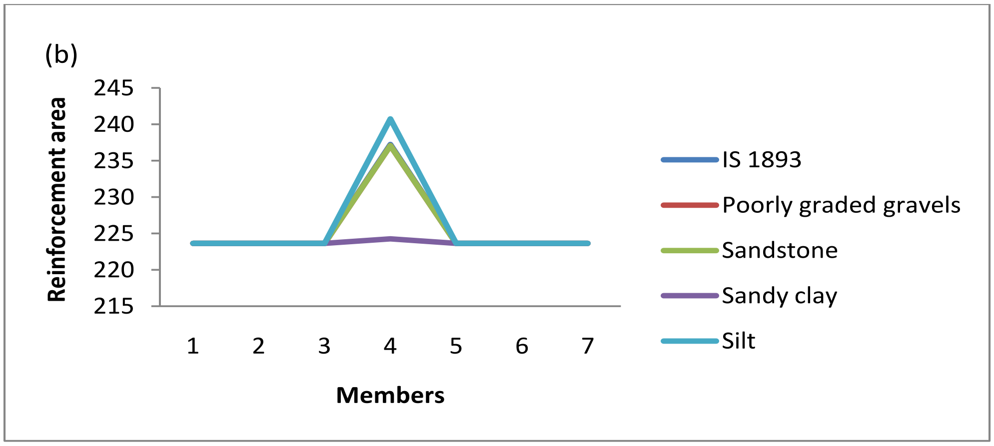
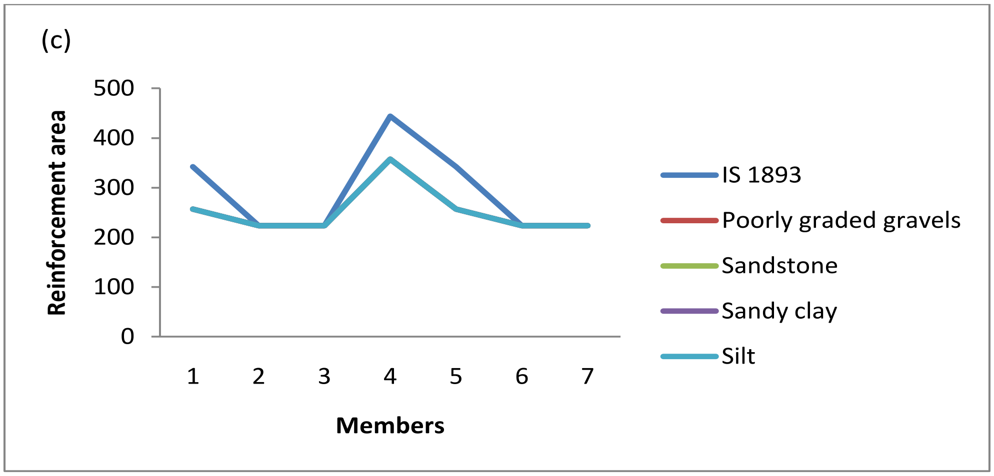


Fig. 4.51: Bending moment of 10th floor beams in KNm with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.51 it was observed that the bending moment at 10th floor beams members for IS 1893 design has highest values in compared to rest of soil in both the directions and poorly graded gravels, sandstone, sandy clay and silt have same values.







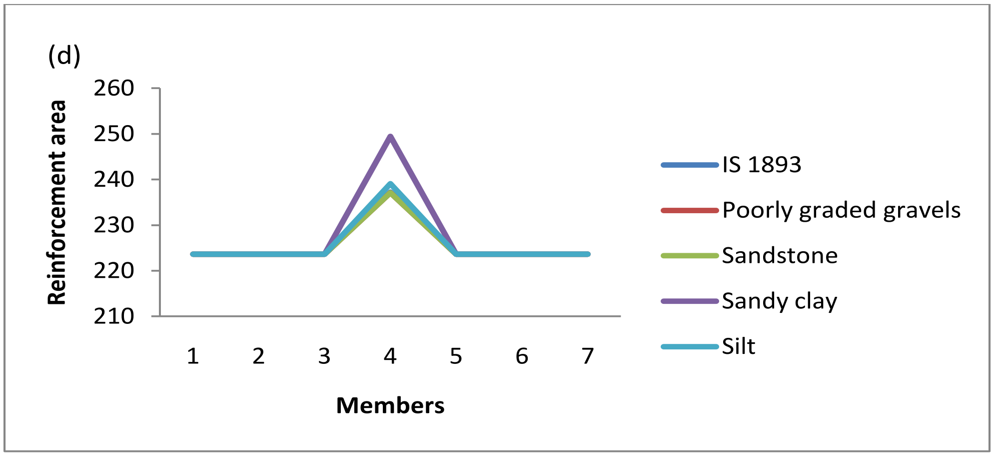


Fig. 4.52: Reinforcement area of 10th floor beams mm^2 with respect to members of the building at 200 PI a) top reinforcement in longitudinal direction b) bottom reinforcement in longitudinal c) top reinforcement in transverse direction d) bottom reinforcement in transverse direction.

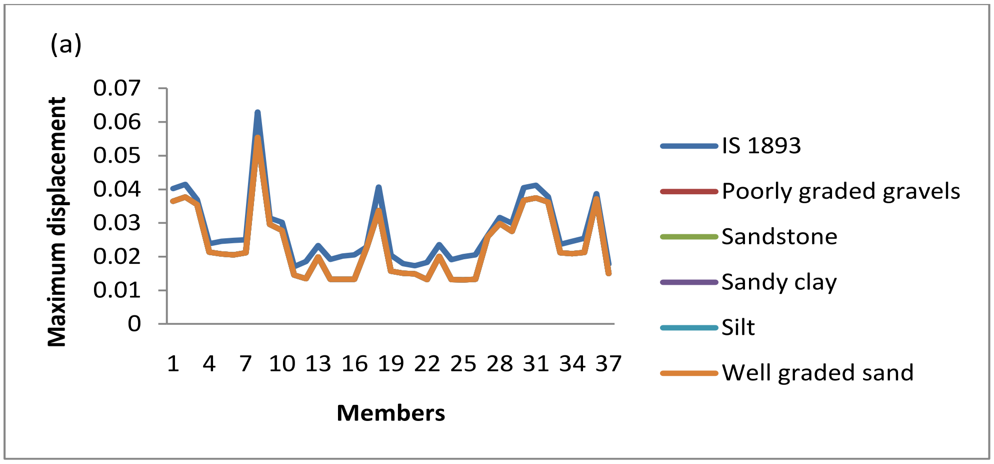
In fig. 4.52 a), IS 1893 has highest value but for member 2, 3, 6 and 7 there values are same for all the types of soil. And the rest of soil has the same value.

In fig. 4.52 b), the reinforcement area has highest value for silt at member 4 and for the rest of members the values remain same.

In fig. 4.52 c), IS 1893 has highest value but for member 2, 3, 6 and 7 there values are same for all the types of soil.

In fig. 4.52 d), the reinforcement area has highest value for sandy clay at member 4 and for the rest of members the values remain same.

Dynamic analysis by response spectrum method for 3 storey structure-



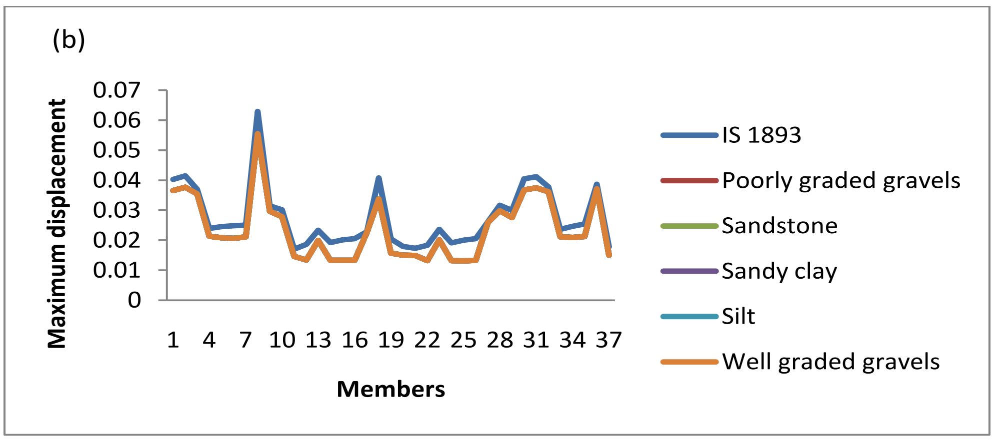
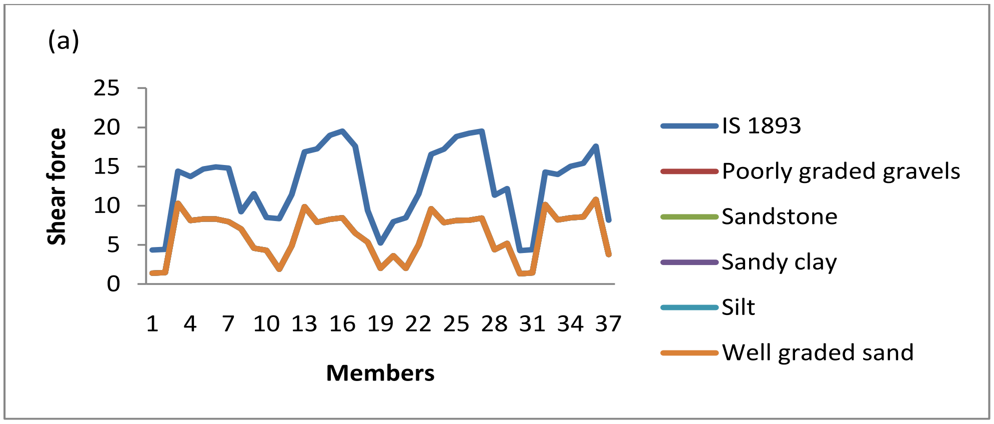


Fig. 4.53: Maximum displacements of column in cm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.53 it was observed that the maximum displacement for IS 1893 design has higher displacement in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay, silt and well graded sand has the same displacement values for both the direction.



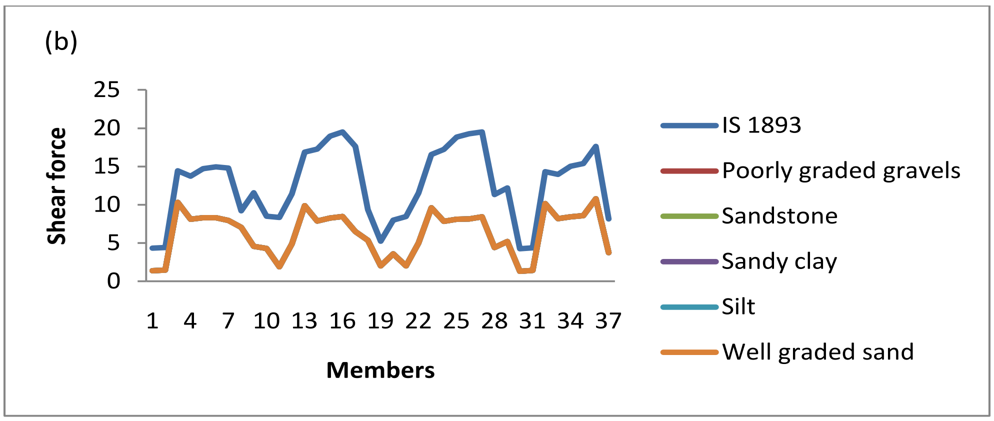
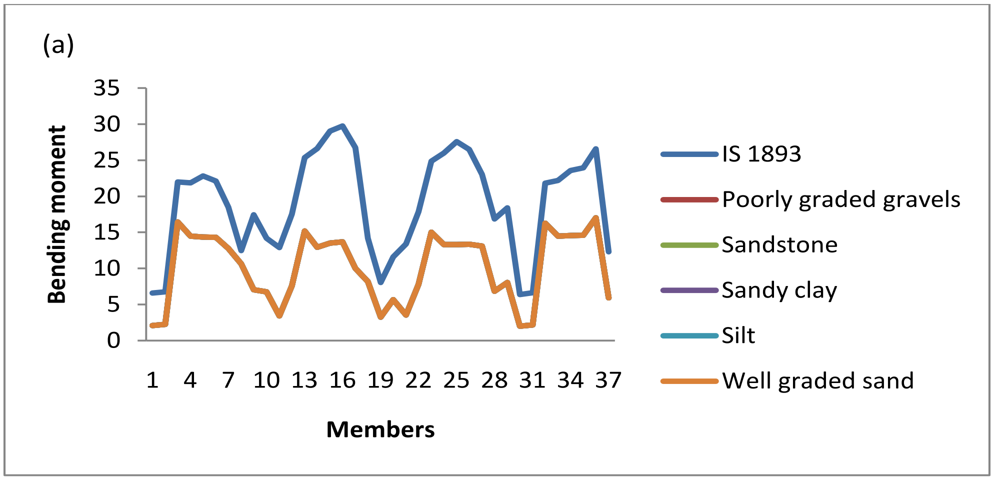


Fig. 4.54: Shear force of column in KN with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.54 it was observed that the shear forces for IS 1893 design has higher values in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay, silt and well graded sand has the same values for both the direction.



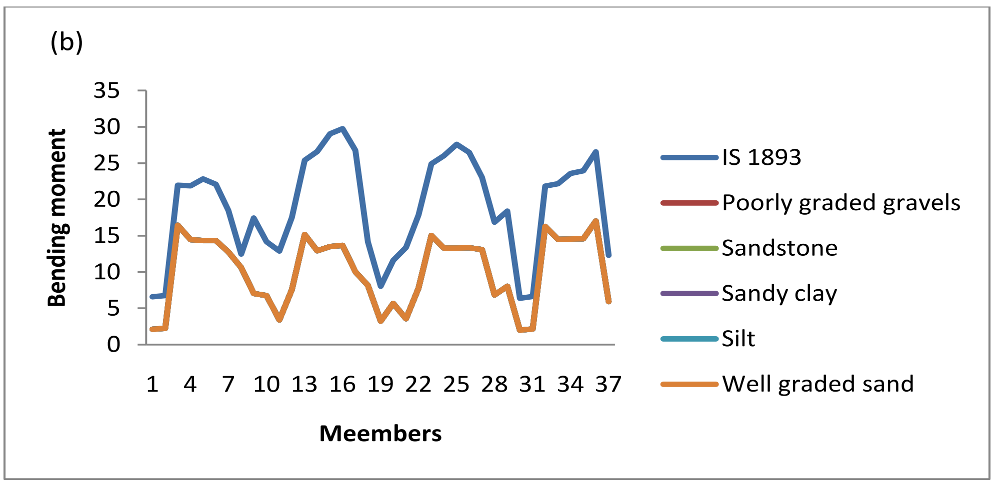
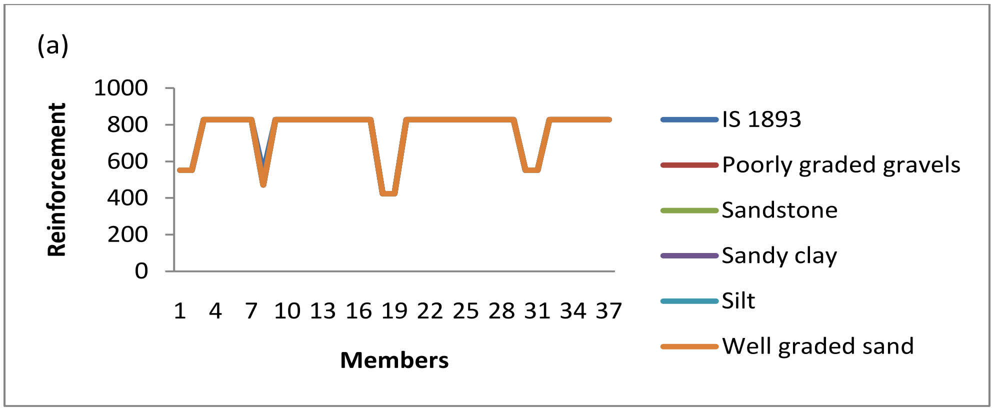


Fig. 4.55: Bending moment of column in KNm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.55 it was observed that the bending moment for IS 1893 design has higher values in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay, silt and well graded sand has the same values for both the direction.



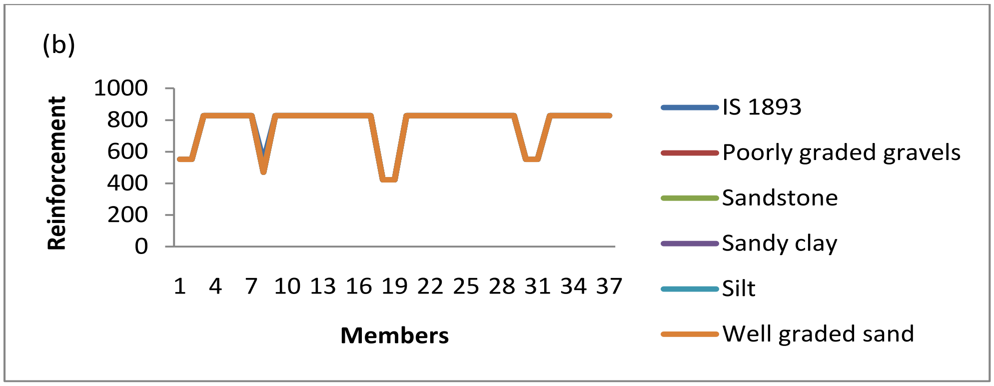
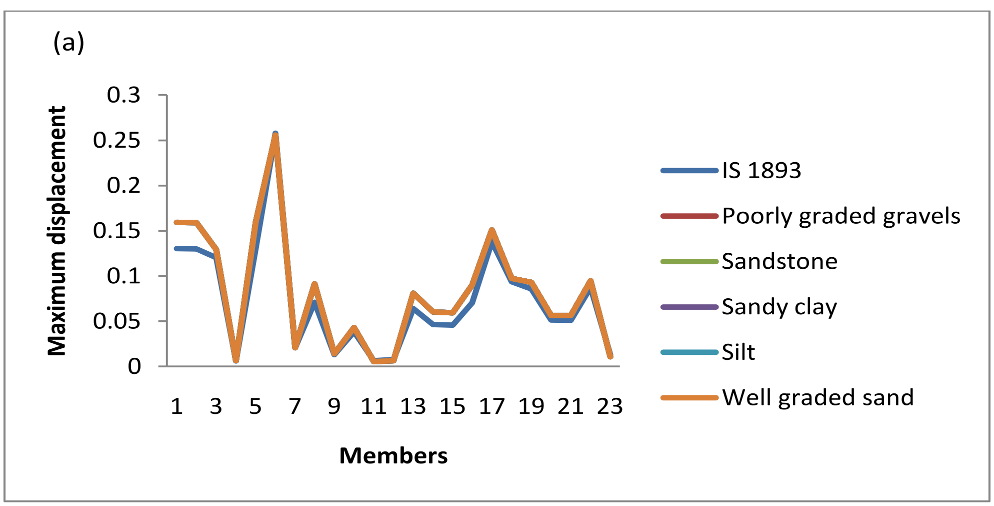


Fig. 4.56 Reinforcement area of column in mm^2 with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.56 it was observed that the reinforcement area in both the direction of propagation is having the same value irrespective of direction and types of soil i.e. having the same value for all the types of soil.



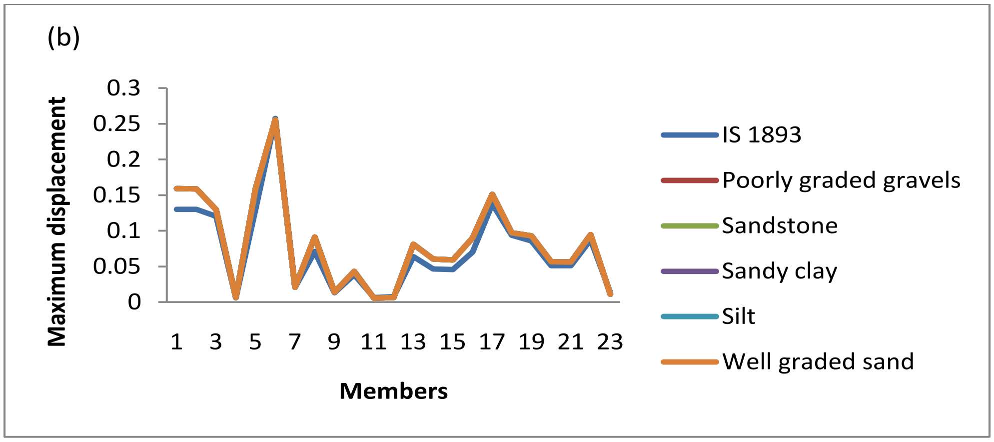
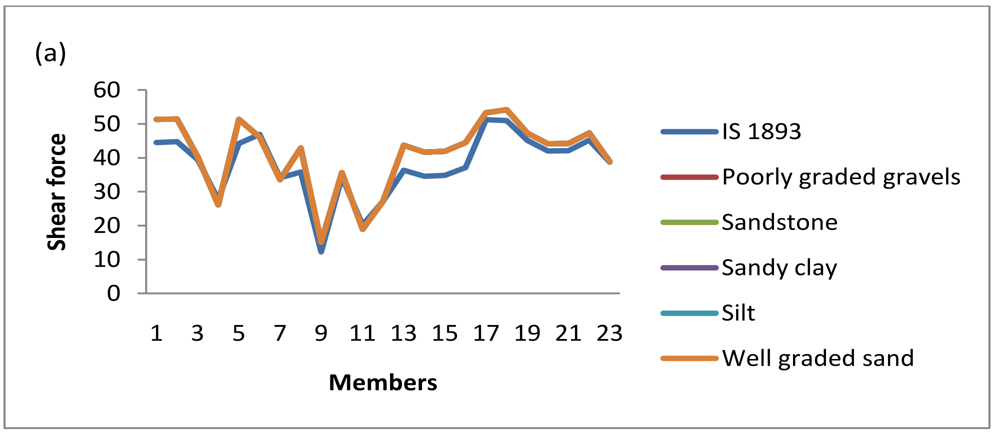


Fig. 4. 57: Maximum displacements of 3rd floor beams in cm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.57 it was observed that the maximum displacement for poorly graded gravels, sandstone, sandy clay, silt and well graded sand is higher comparatively to the IS 1893 design and in some members it's the same for both the propagation direction of seismic waves.



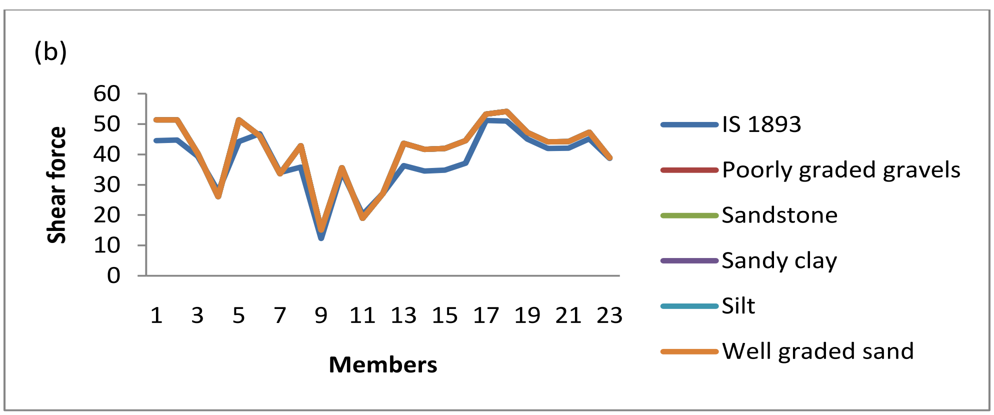


Fig. 4.58: Shear force of 3rd floor beams in KN with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.58 it was observed that the shear forces for poorly graded gravels, sandstone, sandy clay, silt and well graded sand is higher comparatively to the IS 1893 design and in some members it’s the same for both the propagation direction of seismic waves.

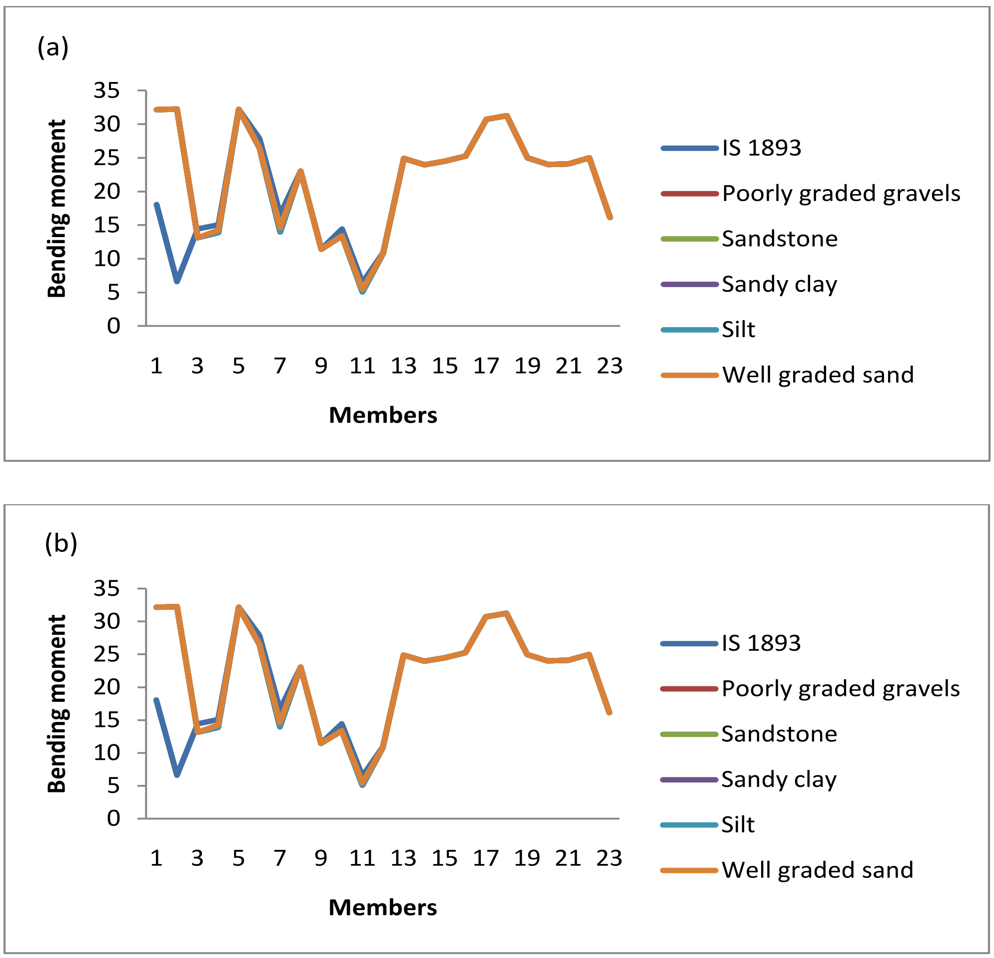
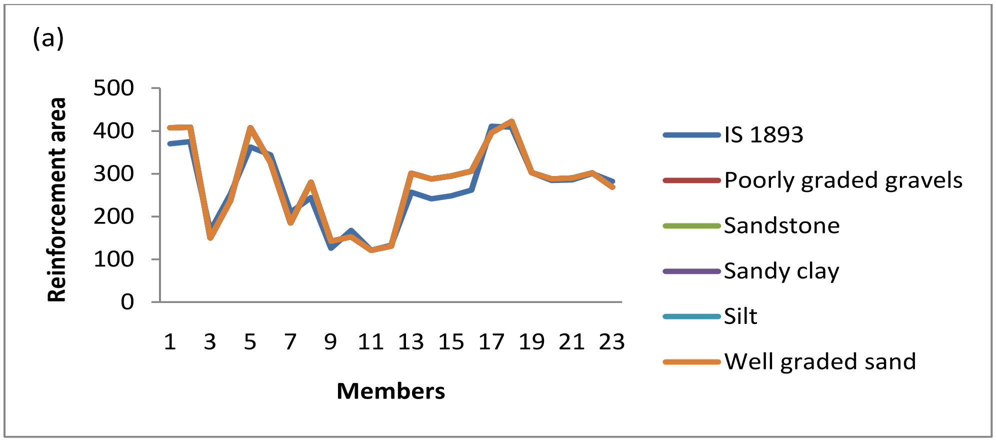
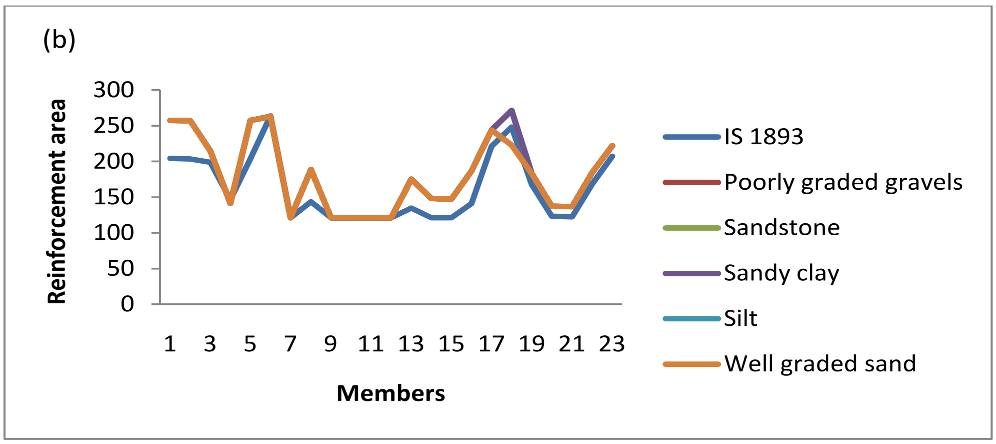
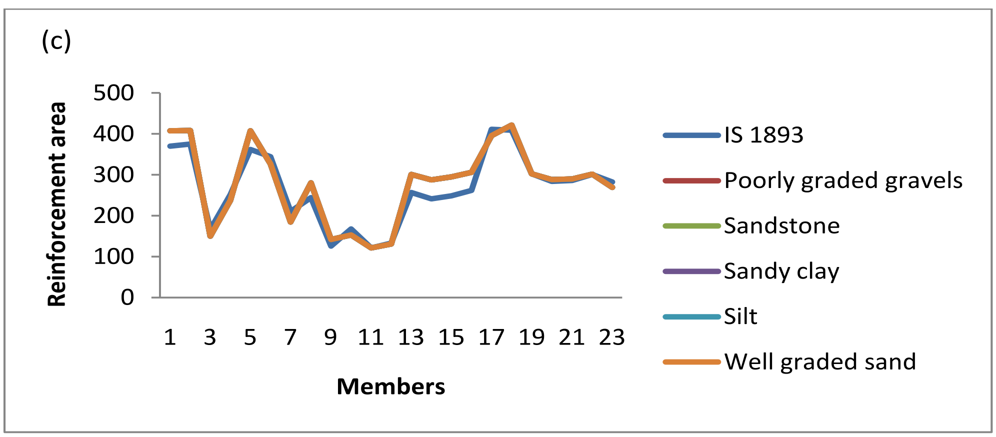


Fig. 4.59: Bending moment of column in KNm with respect to members of the building at 0 PI a) longitudinal direction b) transverse direction.

From fig. 4.59 it was observed that the bending moment for poorly graded gravels, sandstone, sandy clay, silt and well graded sand is higher comparatively to the IS 1893 design and in some members it’s the same for both the propagation direction of seismic waves. Also in members like 3, 4, 5 and 7 the value is lower than the IS 1893 design.


(a)
Reinforcement area
500
400
300
200
100
0
1 3 5 7 9 11 13 15 17 19 21 23
Members
IS 1893
Poorly graded gravels
Sandstone
Sandy clay
Silt
Well graded sand


(b)
Reinforcement area
300
250
200
150
100
50
0
1 3 5 7 9 11 13 15 17 19 21 23
Members
IS 1893
Poorly graded gravels
Sandstone
Sandy clay
Silt
Well graded sand


(c)
Reinforcement area
500
400
300
200
100
0
1 3 5 7 9 11 13 15 17 19 21 23
Members
IS 1893
Poorly graded gravels
Sandstone
Sandy clay
Silt
Well graded sand

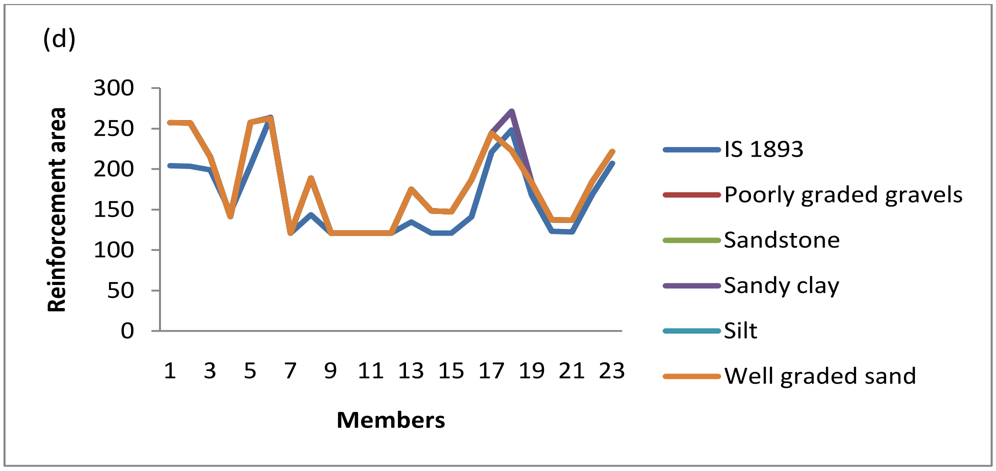


Fig. 4.60: Reinforcement area of 3rd floor beams mm^2 with respect to members of the building at 0 PI a) top reinforcement in longitudinal direction b) bottom reinforcement in longitudinal c) top reinforcement in transverse direction d) bottom reinforcement in transverse direction.

In fig. 4.60 a), the reinforcement area for poorly graded gravels, sandstone, sandy clay, silt and well graded sand have higher value in compared to IS 1893 design but for some members it is lesser.

In fig. 4.60 b), the reinforcement areas in this direction have lesser value in compared to the longitudinal direction. For poorly graded gravels, sandstone, sandy clay, silt and well graded sand have higher value in compared to IS 1893 design but for some members it is lesser.

In fig. 4.60 c), the reinforcement area for both the longitudinal direction is similar and is higher than the other direction. the reinforcement area for poorly graded gravels, sandstone, sandy clay, silt and well graded sand have higher value in compared to IS 1893 design but for some members it is lesser.

In fig. 4.60 d), the reinforcement areas in this direction have lesser value in compared to the longitudinal direction. For poorly graded gravels, sandstone, sandy clay, silt and well graded sand have higher value in compared to IS 1893 design but for some members it is lesser.

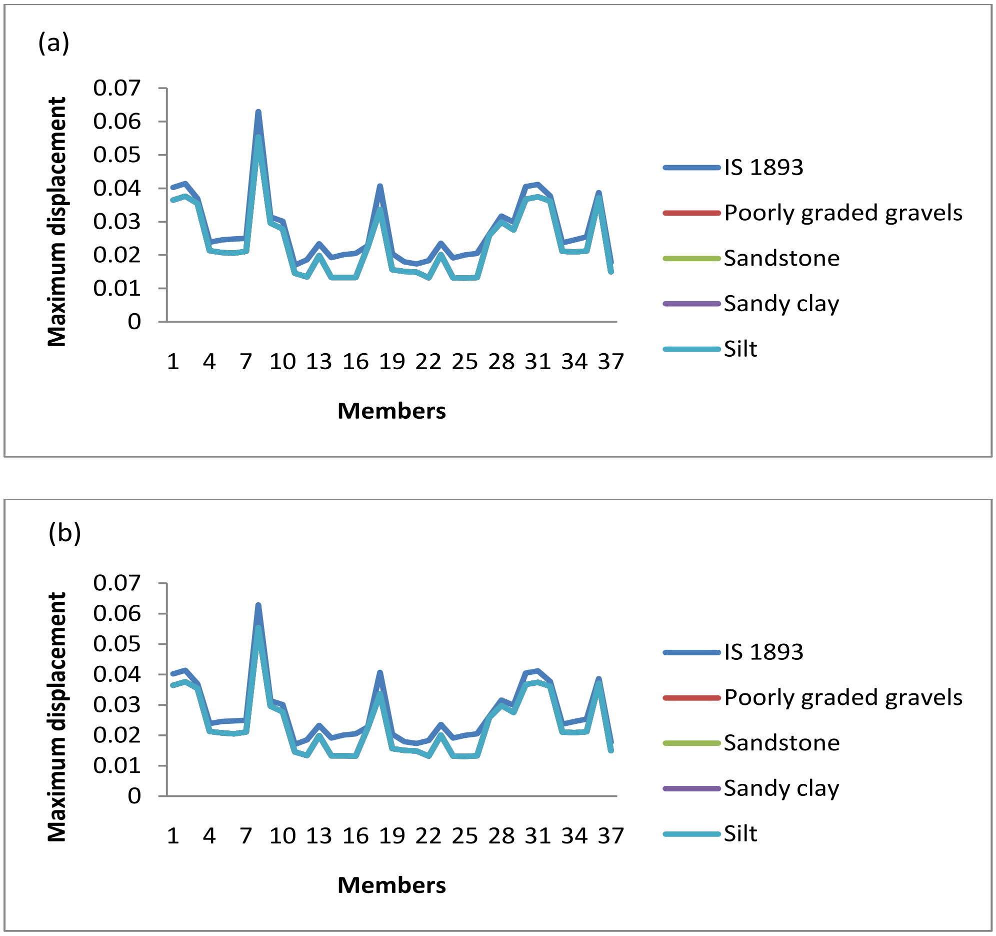
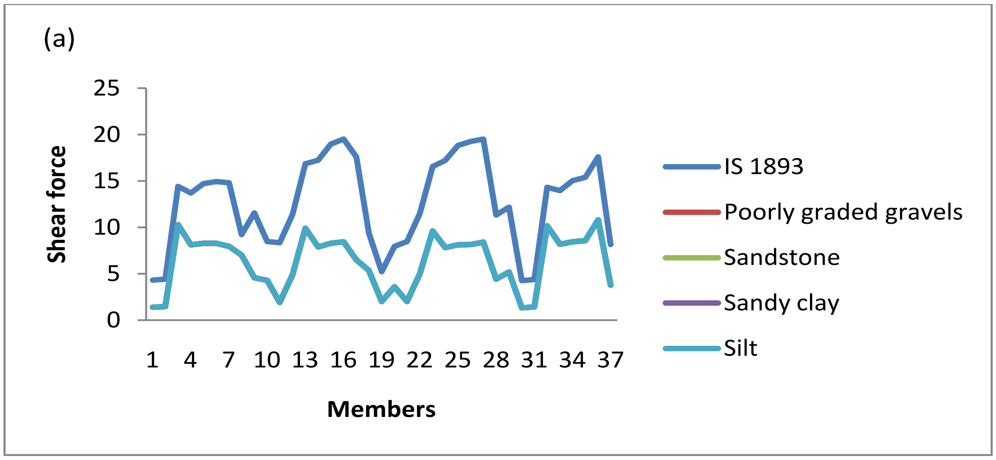


Fig. 4.61: Maximum displacements of column in cm with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.61 it was observed that the maximum displacement for IS 1893 design has higher displacement in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay, silt and well graded sand has the same displacement values for both the direction.



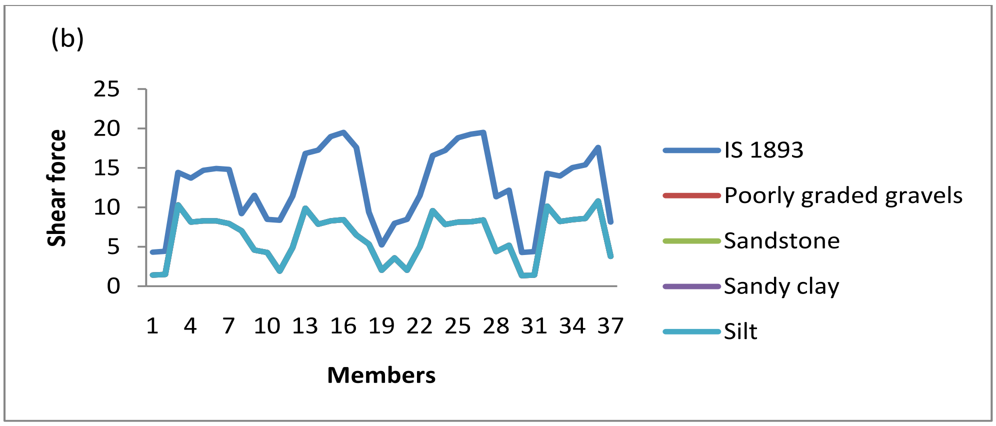
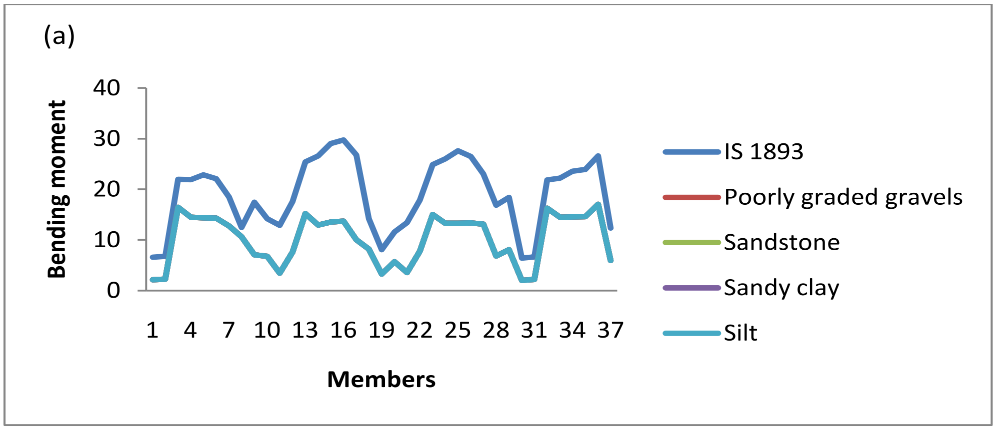


Fig. 4.62: Shear force of column in KN with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.62 it was observed that the shear forces for IS 1893 design has higher values in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay, silt and well graded sand has the same values for both the direction.



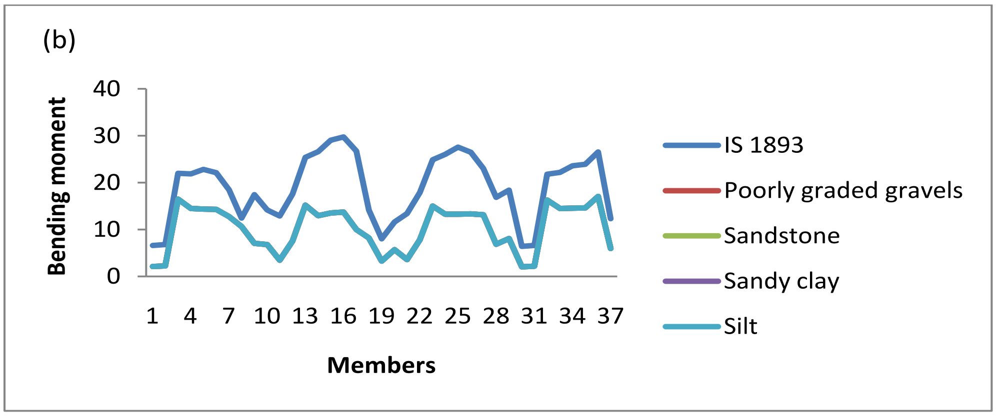
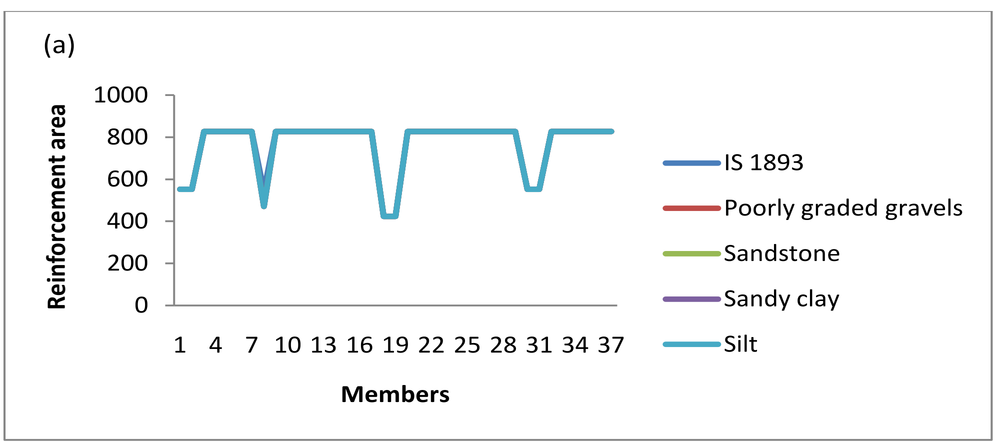


Fig. 4.63: Bending moment of column in KNm with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.63 it was observed that the bending moment for IS 1893 design has higher values in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay, silt and well graded sand has the same values for both the direction.



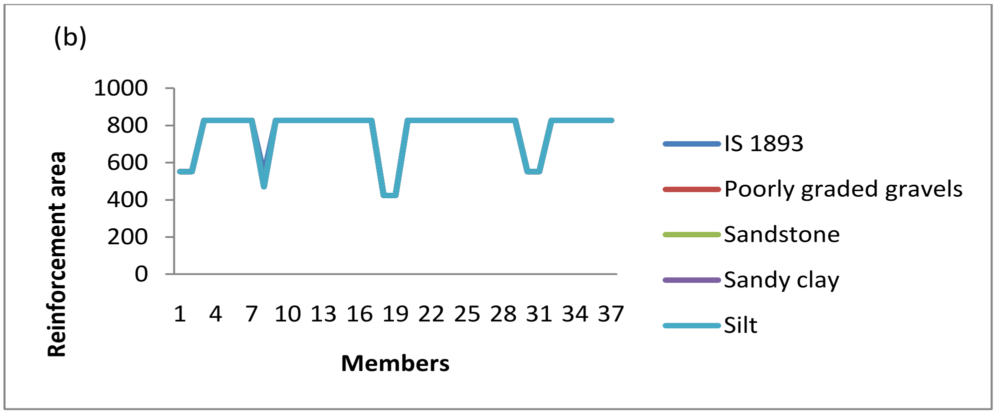
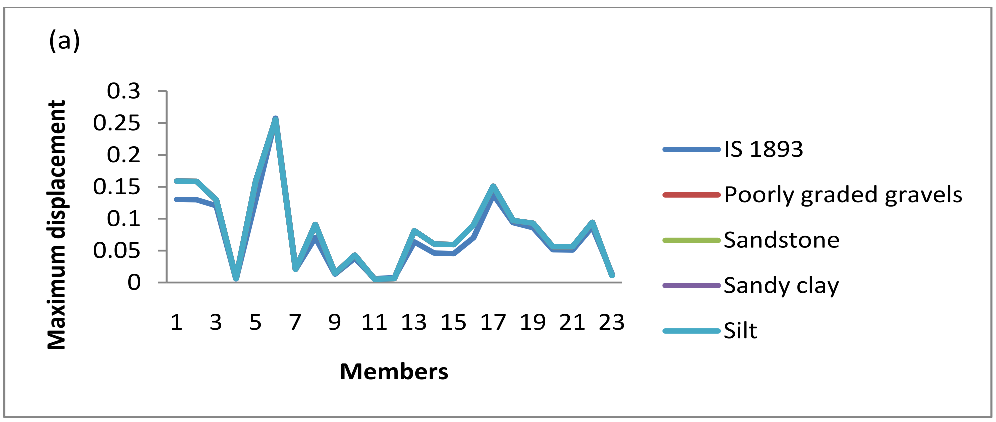


Fig. 4.64: Reinforcement area of column in mm^2 with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.64 it was observed that the reinforcement area in both the direction of propagation is having the same value irrespective of direction and types of soil i.e. having the same value for all the types of soil.



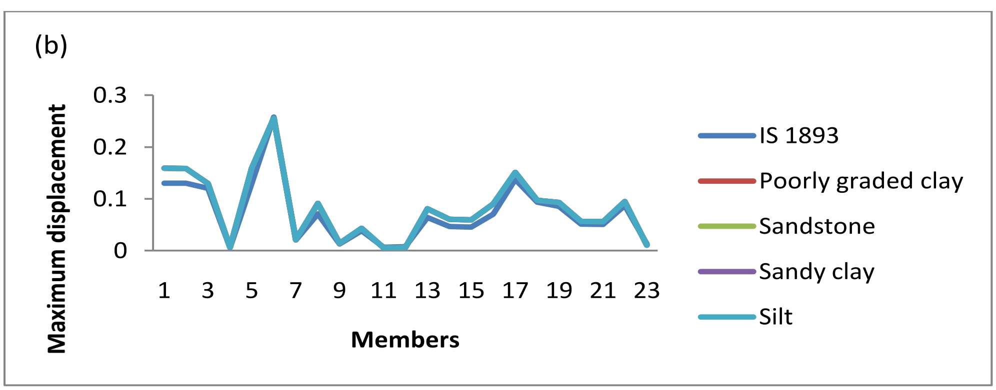


Fig. 4.65: Maximum displacements of 3rd floor beams in cm with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.65 it was observed that the maximum displacement for poorly graded gravels, sandstone, sandy clay and silt is higher comparatively to the IS 1893 design and in some members it’s the same for both the propagation direction of seismic waves.

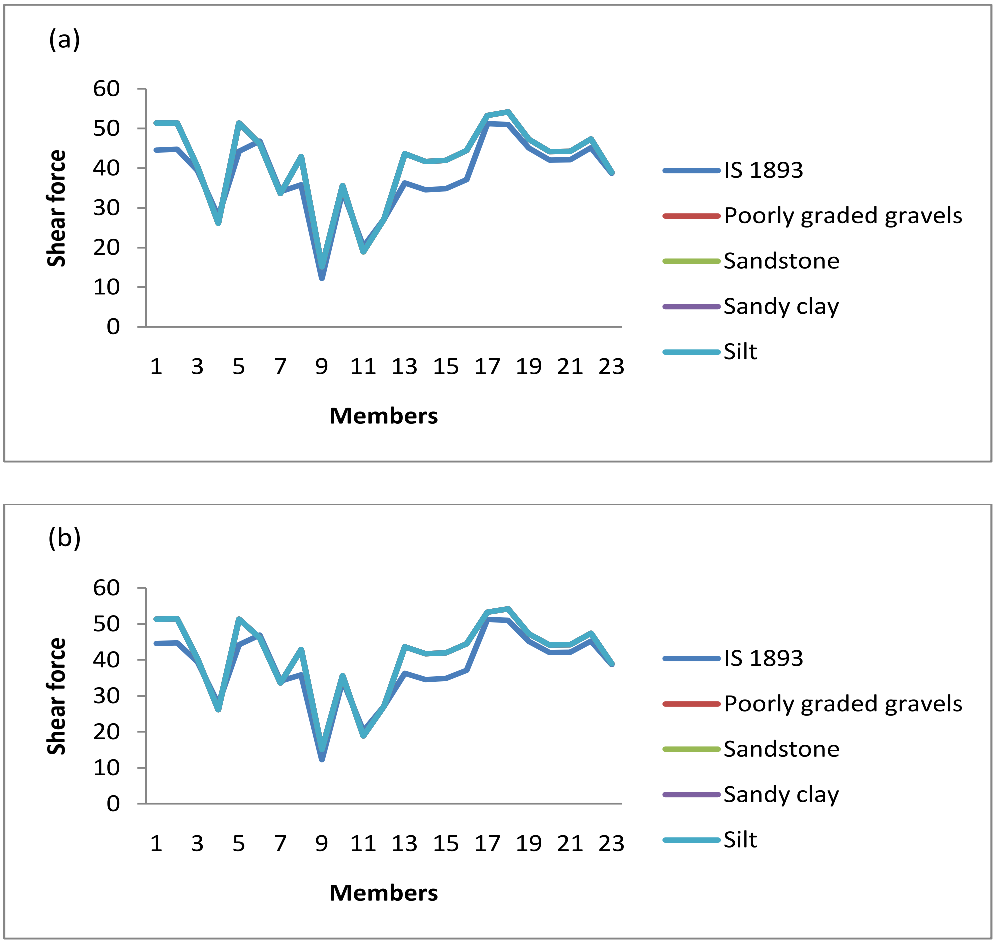


Fig. 4.66: Shear force of 3rd floor beams in KN with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.66 it was observed that the shear forces for poorly graded gravels, sandstone, sandy clay, silt and well graded sand is higher comparatively to the IS 1893 design and in some members it’s the same for both the propagation direction of seismic waves.

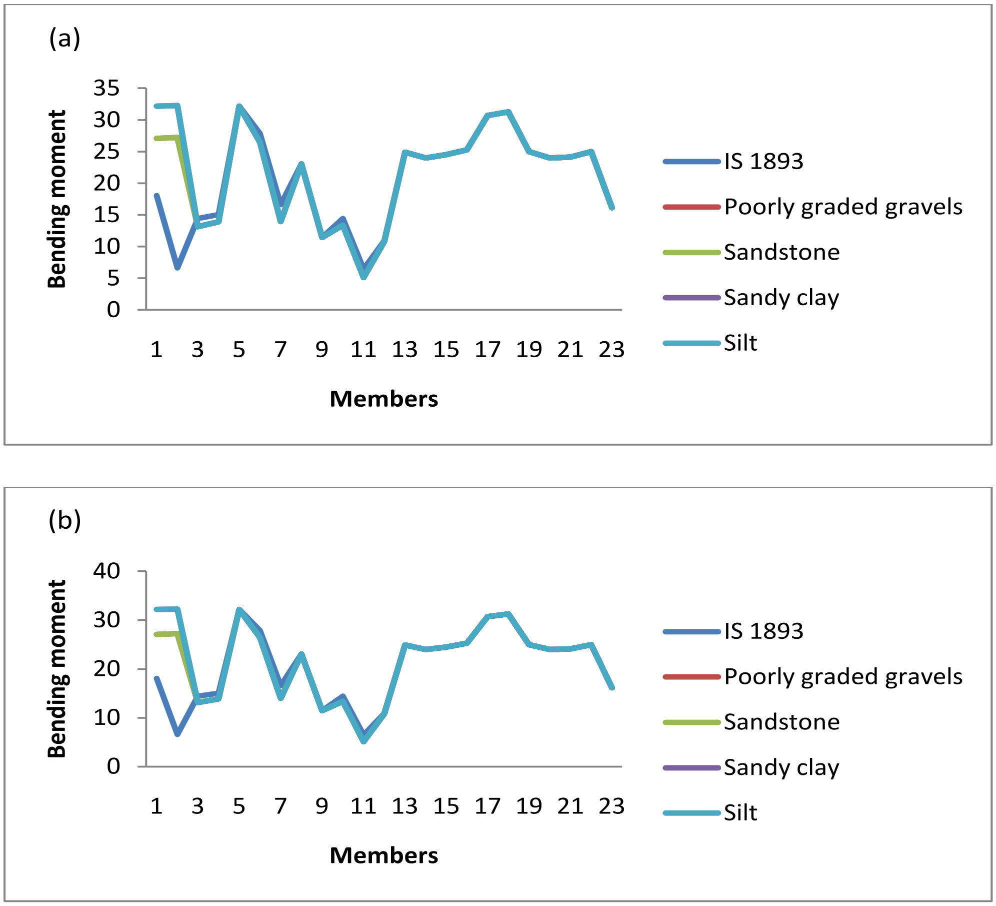
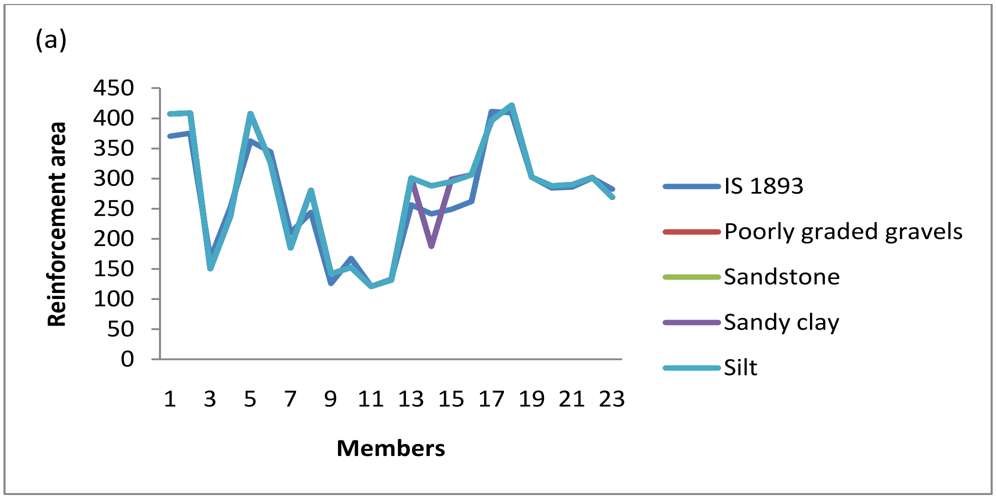
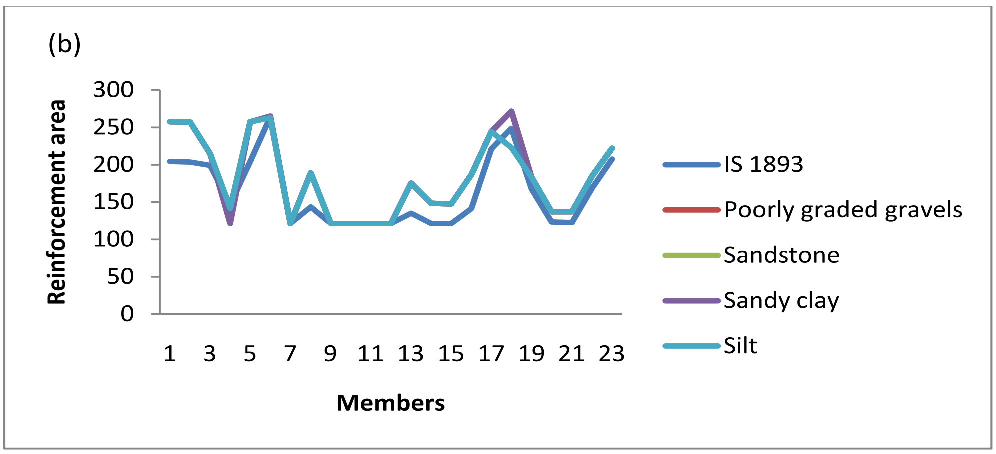
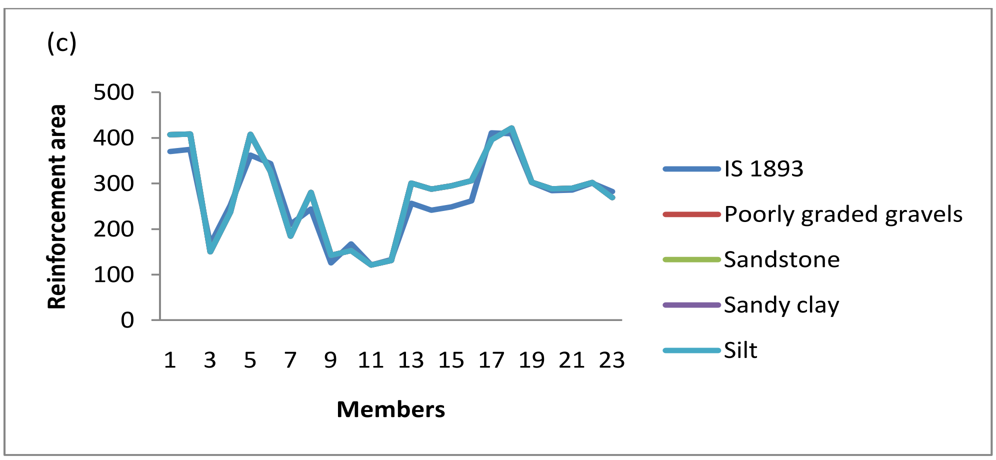


Fig. 4.67: Bending moment of column in KNm with respect to members of the building at 30 PI a) longitudinal direction b) transverse direction.

From fig. 4.67 it was observed that the bending moment for poorly graded gravels, sandstone, sandy clay, silt and well graded sand is higher comparatively to the IS 1893 design and in some members it's the same for both the propagation direction of seismic waves. But also in some members it is seen that the IS 1893 design have higher value.


(a)
450
400
350
300
250
200
150
100
50
0
Reinforcement area
1 3 5 7 9 11 13 15 17 19 21 23
Members
IS 1893
Poorly graded gravels
Sandstone
Sandy clay
Silt


(b)
300
250
200
150
100
50
0
Reinforcement area
1 3 5 7 9 11 13 15 17 19 21 23
Members
IS 1893
Poorly graded gravels
Sandstone
Sandy clay
Silt


(c)
500
400
300
200
100
0
Reinforcement area
1 3 5 7 9 11 13 15 17 19 21 23
Members
IS 1893
Poorly graded gravels
Sandstone
Sandy clay
Silt

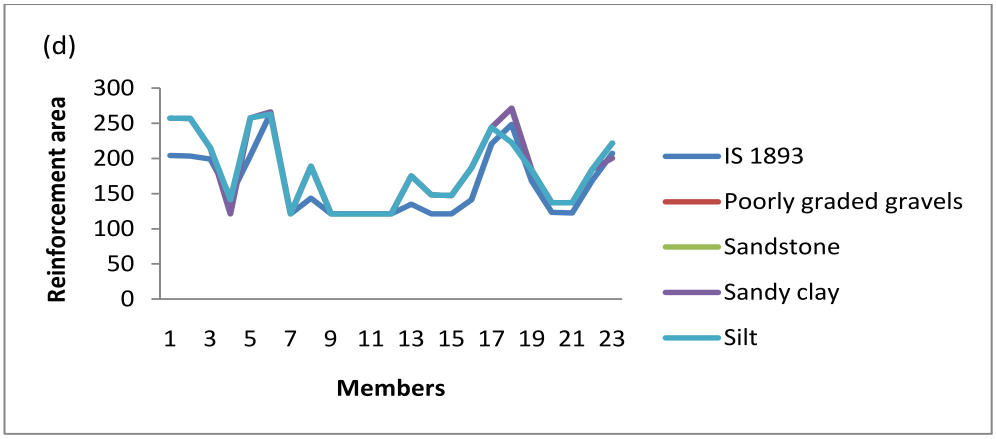


Fig. 4.68: Reinforcement area of 3rd floor beams mm^2 with respect to members of the building at 30 PI a) top reinforcement in longitudinal direction b) bottom reinforcement in longitudinal c) top reinforcement in transverse direction d) bottom reinforcement in transverse direction.

In fig. 4.68 a), the reinforcement area for poorly graded gravels, sandstone, sandy clay and silt have higher value in compared to IS 1893 design but for some members it is lesser.

In fig. 4.68 b), the reinforcement areas in this direction have lesser value in compared to the longitudinal direction. For poorly graded gravels, sandstone, sandy clay and silt have higher value in compared to IS 1893 design but for some members it is lesser.

In fig. 4.68 c), the reinforcement area for both the longitudinal direction is similar and is higher than the other direction. the reinforcement area for poorly graded gravels, sandstone, sandy clay and silt have higher value in compared to IS 1893 design but for some members it is lesser.

In fig. 4.68 d), the reinforcement areas in this direction have lesser value in compared to the longitudinal direction. For poorly graded gravels, sandstone, sandy clay and silt have higher value in compared to IS 1893 design but for some members it is lesser.

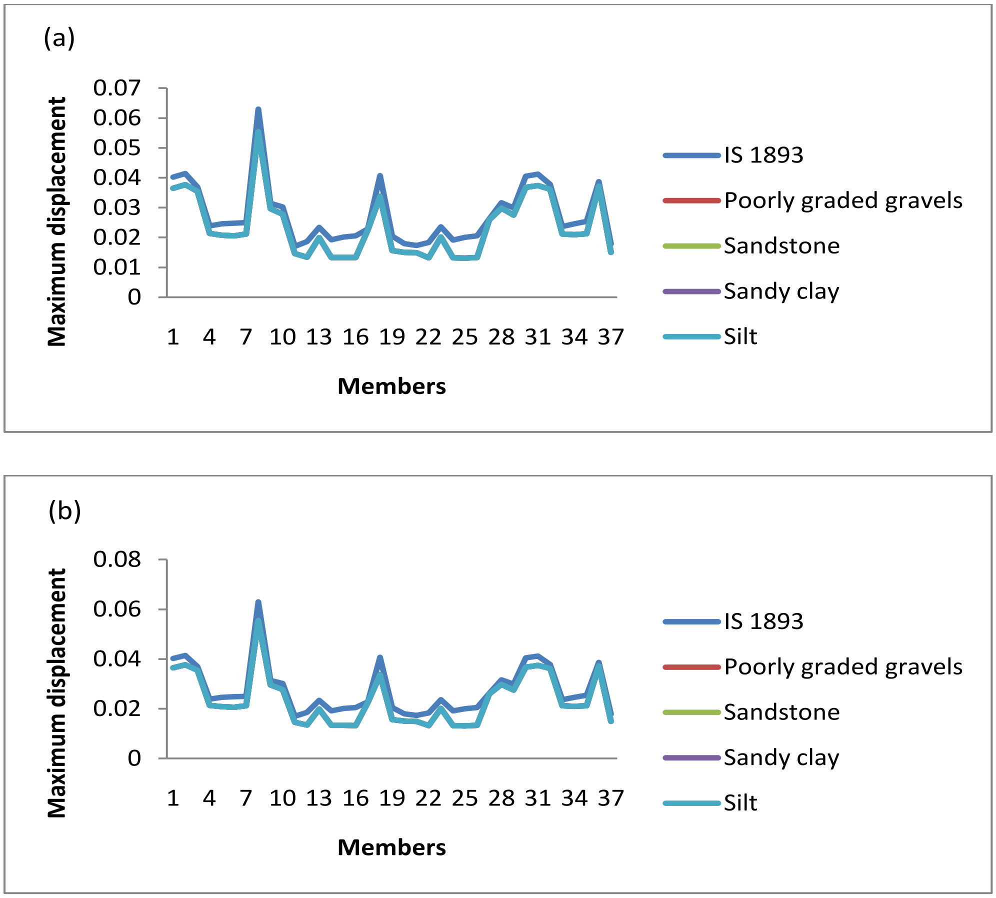
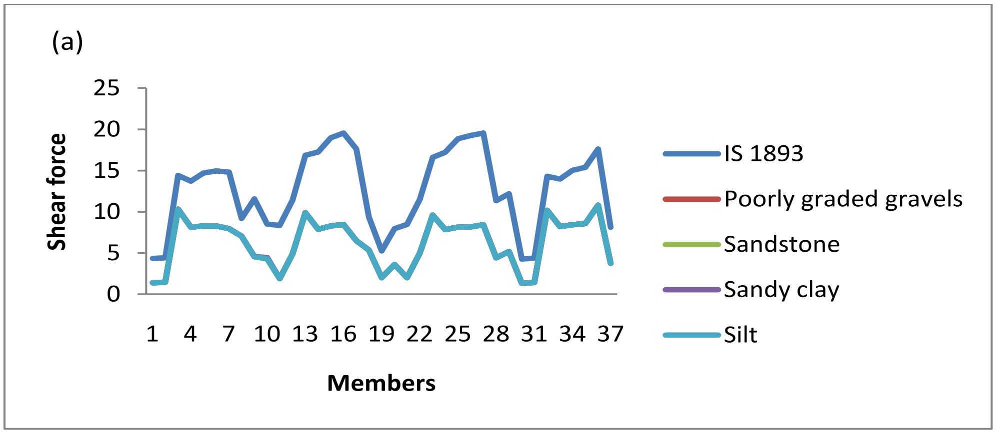


Fig. 4.69: Maximum displacements of column in cm with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.69 it was observed that the maximum displacement for IS 1893 design has higher displacement in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same displacement values for both the direction.



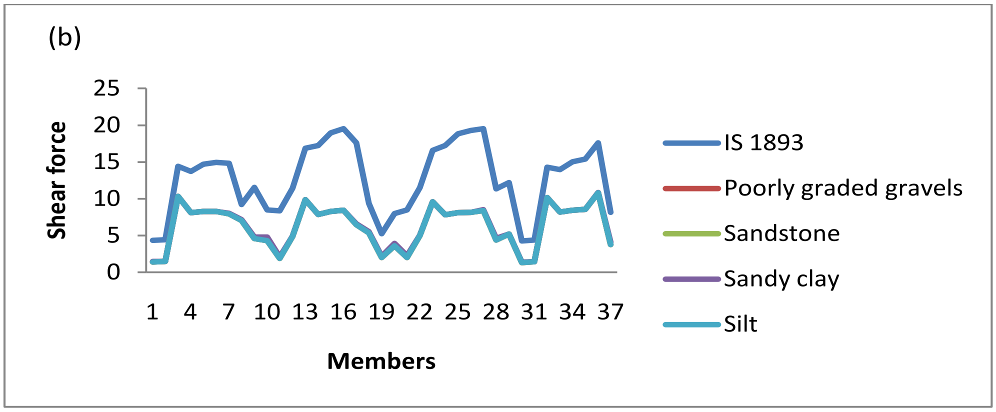


Fig. 4.70: Shear force of column in KN with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.70 it was observed that the shear forces for IS 1893 design has higher values in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values for both the direction.

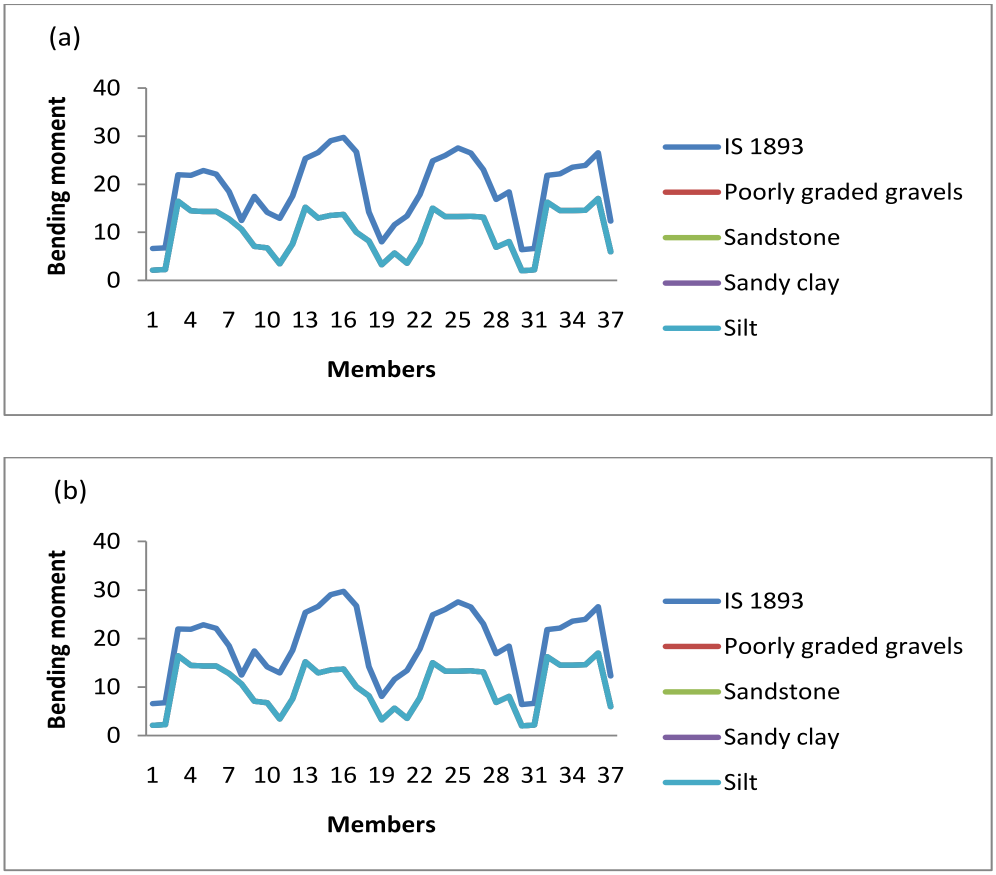
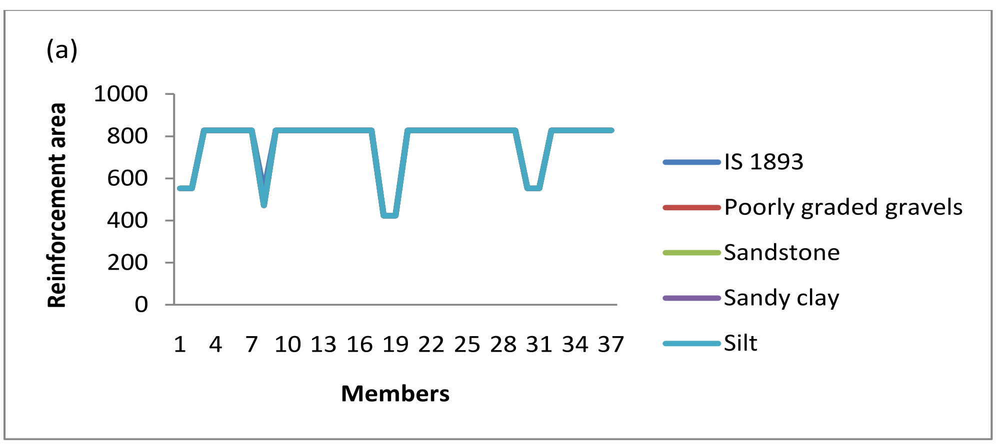


Fig. 4.71: Bending moment of column in KNm with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.71 it was observed that the bending moment for IS 1893 design has higher values in compared to all the other types of soil in both the direction of seismic wave propagation. The poorly graded gravels, sandstone, sandy clay and silt has the same values for both the direction.



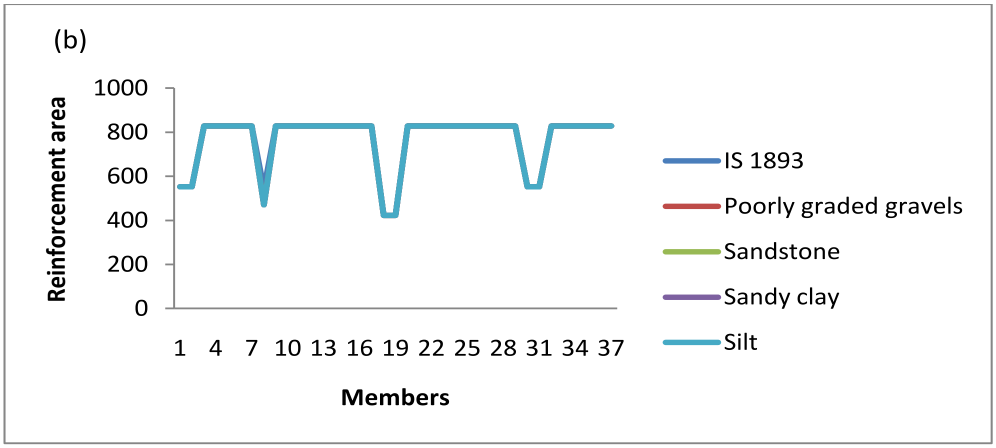
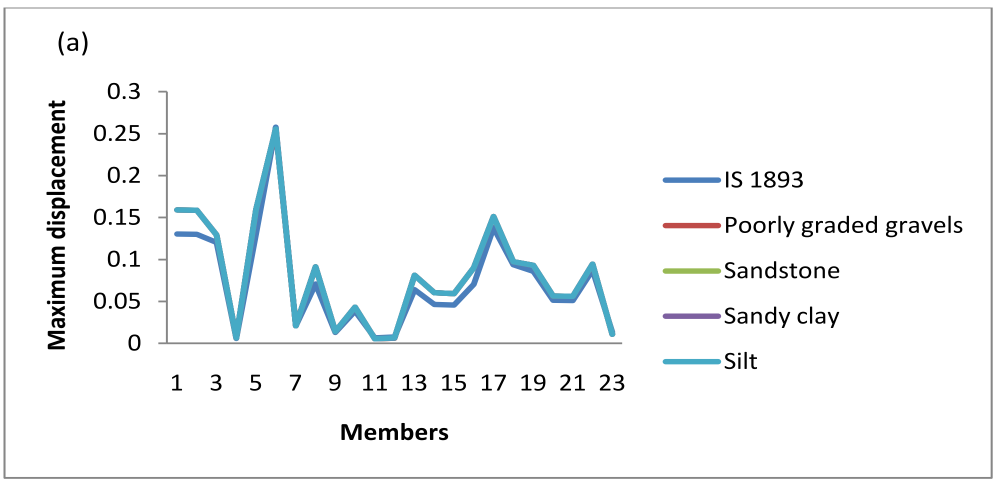


Fig. 4.72: Reinforcement area of column in mm^2 with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.72 we find that the reinforcement area in both the direction of propagation is having the same value irrespective of direction and types of soil i.e. having the same value for all the types of soil.



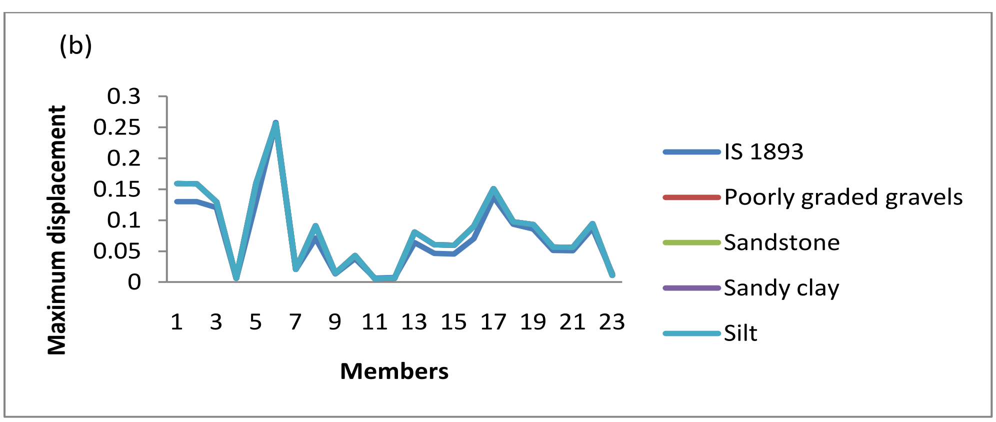
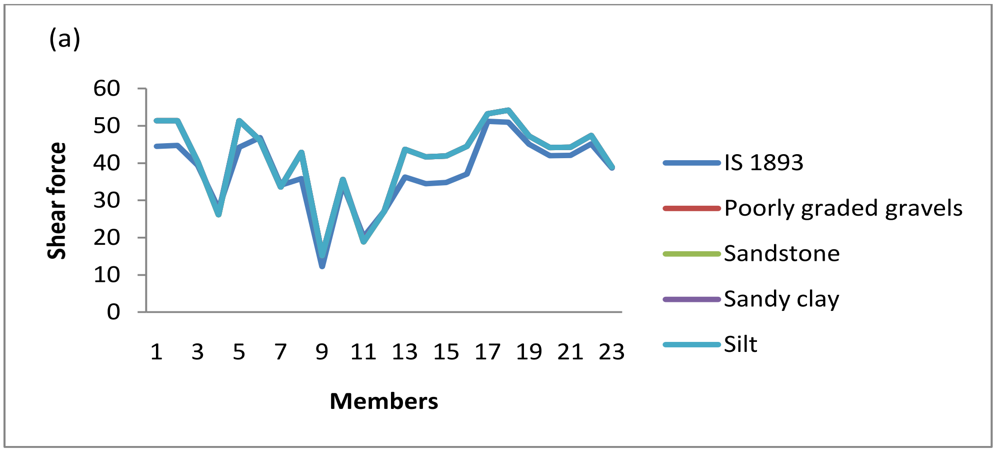


Fig. 4.73: Maximum displacements of 3rd floor beams in cm with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.73 it was observed that the maximum displacement for poorly graded gravels, sandstone, sandy clay, silt and well graded sand is higher comparatively to the IS 1893 design and in some members it's the same for both the propagation direction of seismic waves.



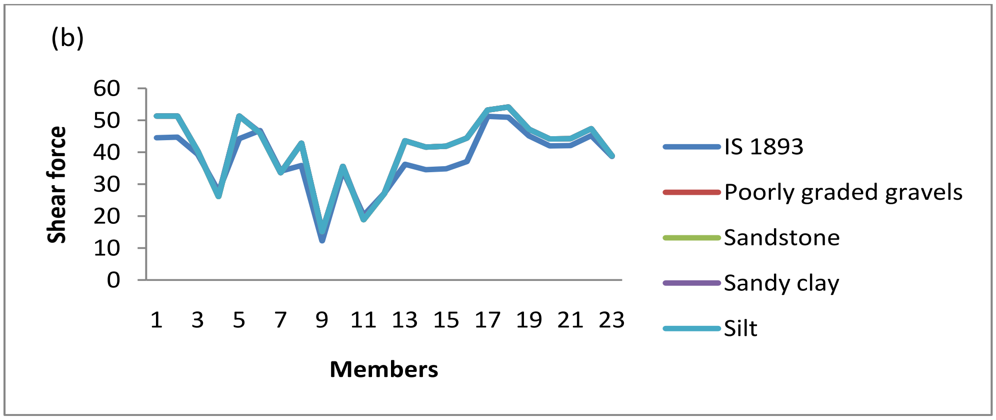
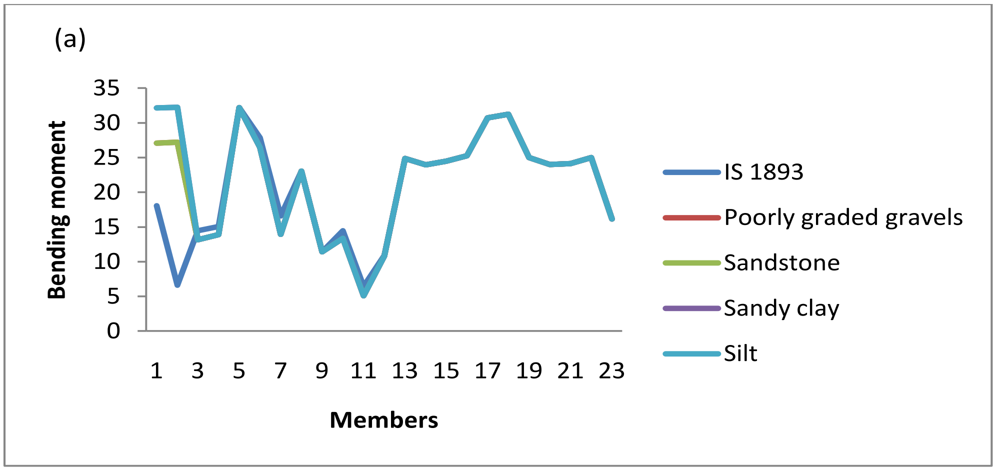


Fig. 4.74: Shear force of 3rd floor beams in KN with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.74 it was observed that the shear forces for poorly graded gravels, sandstone, sandy clay, silt and well graded sand is higher comparatively to the IS 1893 design and in some members it's the same for both the propagation direction of seismic waves.



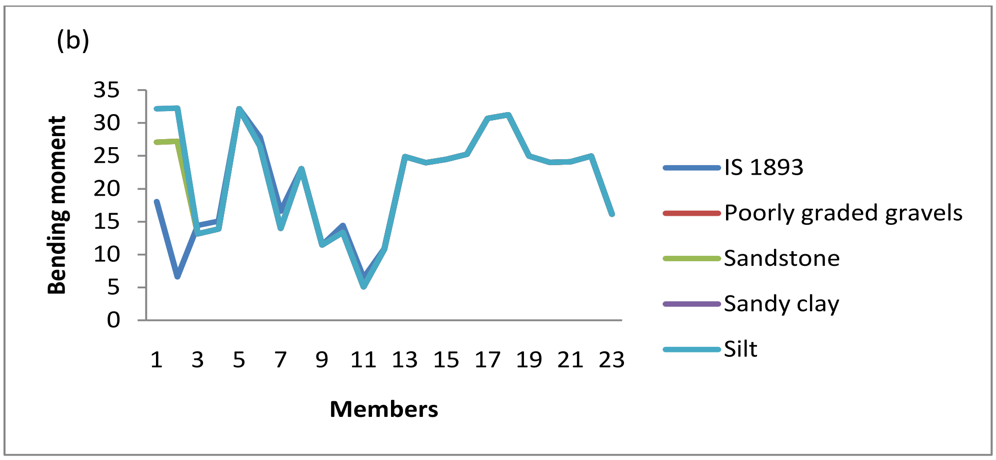
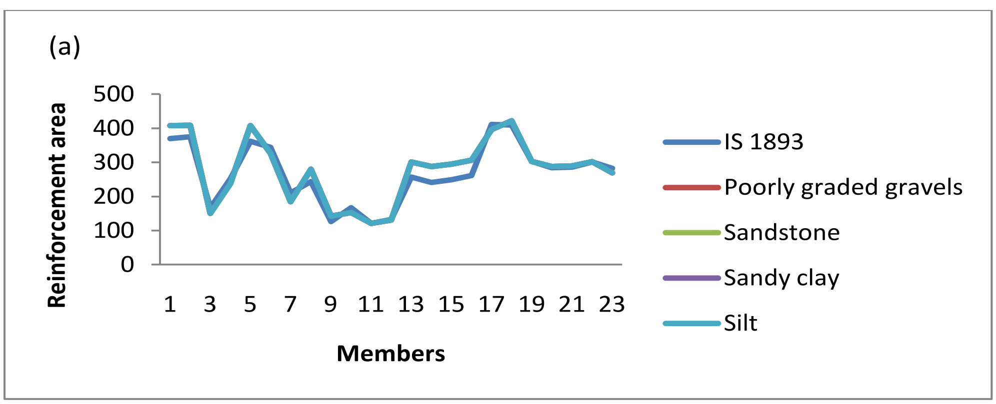
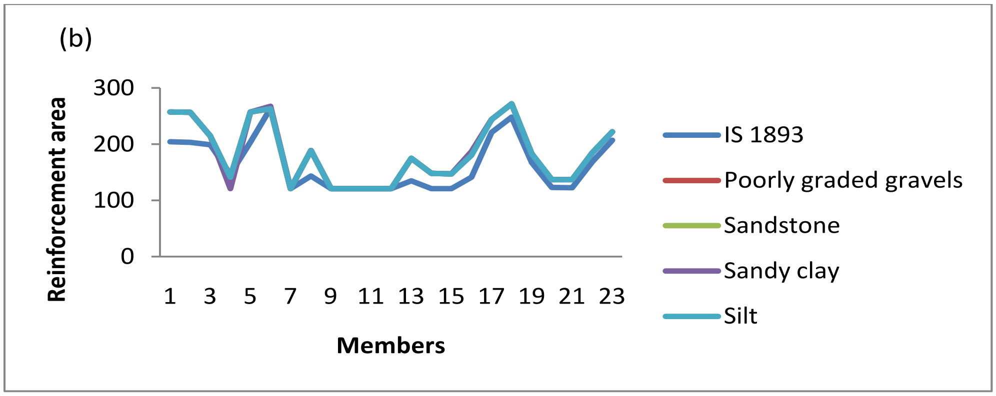
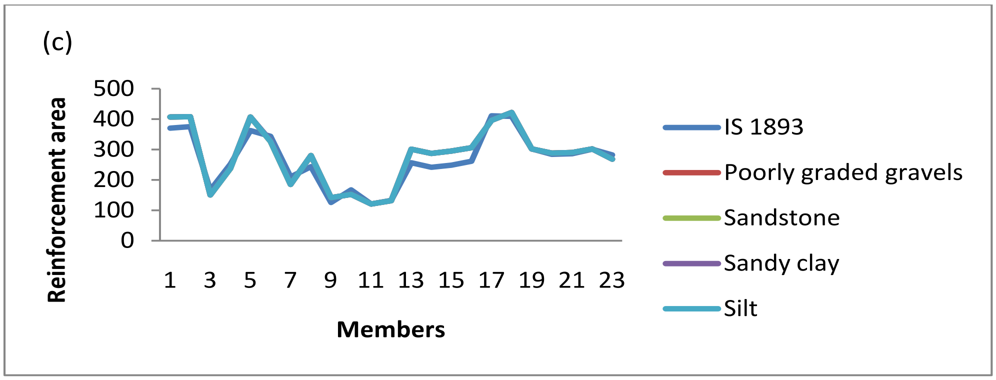


Fig. 4.75: Bending moment of column in KNm with respect to members of the building at 200 PI a) longitudinal direction b) transverse direction.

From fig. 4.75 it was observed that the bending moment for poorly graded gravels, sandstone, sandy clay and silt is higher comparatively to the IS 1893 design and in some members it's the same for both the propagation direction of seismic waves.







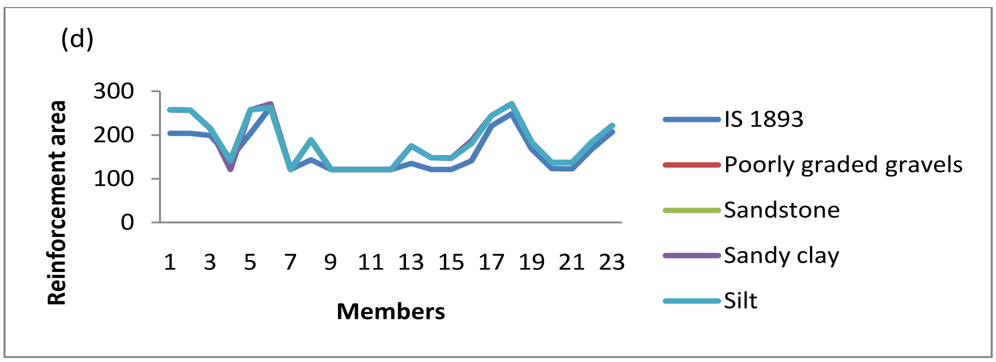


Fig. 4.76: Reinforcement area of 3rd floor beams mm^2 with respect to members of the building at 200 PI a) top reinforcement in longitudinal direction b) bottom reinforcement in longitudinal c) top reinforcement in transverse direction d) bottom reinforcement in transverse direction.

In fig. 4.76 a), the reinforcement area for poorly graded gravels, sandstone, sandy clay, silt and well graded sand have higher value in compared to IS 1893 design but for some members it is lesser.

In fig. 4.76 b), the reinforcement areas in this direction have lesser value in compared to the longitudinal direction. For poorly graded gravels, sandstone, sandy clay and silt have higher value in compared to IS 1893 design but for some members it is lesser.

In fig. 4.76 c), the reinforcement area for both the longitudinal direction is similar and is higher than the other direction. the reinforcement area for poorly graded gravels, sandstone, sandy clay and silt have higher value in compared to IS 1893 design but for some members it is lesser.

In fig. 4.76 d), the reinforcement areas in this direction have lesser value in compared to the longitudinal direction. For poorly graded gravels, sandstone, sandy clay and silt have higher value in compared to IS 1893 design but for some members it is lesser.

CHAPTER 5

Conclusions

CHAPTER - 5

Conclusions

In the present study an attempt has been made to generate response spectra using site specific soil parameters for some sites in seismic zone V, i.e. Arunachal Pradesh and Meghalaya and the generated response spectra is used to analyze some structures using commercial software STAAD Pro. The effect of soil properties, its types and the depth of soil in the response spectrum is discussed using Educational Version of the Oasys Siren software. The response spectrum is obtained from Siren 8.2 in which the physical properties and time history data of an earthquake i.e. North-East earthquake of September 10, 1986 which had the magnitude of 5.2 is considered. Based on the studies conducted from Chapter 2 to Chapter 5 following conclusions are drawn.

5.1 CONCLUSIONS:

(i) The response spectral graph for the Sandy clay is highest in comparison to the other types of soil i.e. poorly graded gravels, sandstone, silt and well graded sadn.

(ii) As the Plasticity Index of the soil increases the absolute acceleration of the soil gets enhanced with respect to the period.

(iii) Plasticity Index value is directly proportional to the response spectra of a particular type of soil.

(iv) The maximum displacement, Shear forces, Bending moment and the Reinforcement area as per IS 1893 soft soil has higher value in comparison to all the other types of soil in both the direction of seismic wave propagation at 0 Plasticity Index value for columns.

(v) The poorly graded gravels, sandstone, sandy clay and silt has the same displacement values, shear forces, bending moment and reinforcement area at 0 Plasticity Index value in both the direction of propagation for columns. The well graded sand has the least for both the direction in columns.

(vi) The trend continues for both the building for all the 3 plasticity index values that were considered and for beams as well.

(vii) Hence, there is a need of analyzing building using site specific response spectra instead of the spectra as per IS 1893.

5.2 SCOPE FOR FUTURE WORK:

In this a preliminary attempt has been made to study the effect of using site specific response spectra instead of using as per IS 1893. However, the study is very limited to a particular earthquake history and for few soil types. Hence, there is a need to go for such study for

(i) Other types of soil conditions and different building geometry.

(ii) Using dynamic analysis using the site specific earthquake spectra

(iii) Development of response spectra considering other relevant soil properties.

References

References

[1] Paz M, editor. International handbook of earthquake engineering. Codes, programs, and examples. New York: Chapman and Hall, 1994.

[2] Sokolov V.Y., "Site & region-specific response spectra: a probabilistic approach", Soil Dynamics and Earthquake Engineering, vol. 20 (2000): pp. 273-281.

[3] Shrikhande M., Basu S., and Kumar A., "Earthquake Strong Motion Data Processing", Department of Earthquake Engineering, IIT, Roorkee, (2001).

[4] Meng J., "Earthquake ground motion simulation with frequency–dependent soil properties", Soil Dynamics and Earthquake Engineering, vol. 27 (2007): pp. 234–241.

[5] International Building Code Council, International Building Code. Falls Church, VA, 2003.

[6] BIS, IS 1893 (Part 1): (2002), "Criteria for Earthquake Resistant Design of Structures Part 1 General Provisions and Buildings", Bureau of Indian Standards, Fifth revision.

[7] Martin GR, Dobry R., "Earthquake site response and seismic code provisions", NCEER Bull 8 (1994): pp. 1–6.

[8] Borcherdt RD, "Estimates of site-dependent response spectra for design (methodology and justification)", Earthquake Spectra EERI vol. 10 (1994): pp. 617–53.

[9] Seed HB, Idriss IM, "Soil moduli and damping factors for dynamic response analyses", Berkeley, CA: Earthquake Research Center, University of California; (1969): (EERC 70-10).

[10] Leroueil S, Marques MES., "State of the art: importance of strain rate and temperature effects in geotechnical engineering, measuring and modeling time dependent soil behavior", In: ASCE Geotechnical special publication no. 61, New York, (1994): pp.1–60.

[11] Stokoe KHI, Darendeli MB, Andrus RD, Brown LT., "Dynamic soil properties: laboratory, field and correlation studies", In: The second international conference on earthquake geotechnical engineering, Lisboa, Potugal, (1999): pp. 811–45.

[12] Shibuya S, Mitachi T., "Strain-rate effects on shear modulus and damping of normally consolidated clay", Geotech Test J 18(3) (1995): pp. 365–75.

[13] Housner, G.W., "Calculating the Response of an Oscillator to Arbitrary Ground Motion", Bulletin of the Seismological Society of America, 31 (1941): pp. 143-149.

[14] Agarwal P. and Shrikhande M.," Earthquake Resistant Design of Structures", PHI Publication, 2004.

[15] Seed, H.B., Idriss, I.M., "Ground motions and liquefaction during earthquakes monograph series", Earthquake Engineering Research Institute, El Cerrito, California (1982).

[16] Mammo T., "Site-specific ground motion simulation and seismic response analysis at the proposed bridge sites within the city of Addis Ababa, Ethiopia", Engineering Geology 79 (2005): pp. 127-150.

[17] Silva W. and Costantino C., "Development of site-specific design ground motions in Western and Eastern North America", Soil Dynamics and Earthquake Engineering 22 (2002): pp. 755-764.

[18] Chandler A. and Lam N., "An attenuation model for distant earthquakes", Earthquake Engineering Structural Dynamics 33 (2004): pp. 183–210.

[19] Bakir P. G., Roeck G. D., Degrande G. and Wong K. K. F., "Site dependent response spectra and analysis of the characteristics of the strong ground motion due to the 1999 Duzce earthquake in Turkey", Engineering Structures 29 (2007): pp. 1939-1956.

[20] Hao H. and Gaull B. A., "Estimation of strong seismic ground motion for engineering use in Perth Western Australia", Soil Dynamics and Earthquake Engineering 29 (2009): pp. 909-924.